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CONTENTS

PAGE

Frontispiece: High-voltage Direct-current Locomotive and Train on the Spanish Northern Railway . . . 646

Editorials: Charles Proteus Steinmetz: A Tribute
Gas and Oil Electric Cars and Locomotives . . . 647

Steinmetz in Fullerton Hall . . . 648
By T. G. PRICE

Extinction of Fires in Generators by Means of Carbon Dioxide . . . 650
By C. L. JONES

The 3000-volt Electrification of the Spanish Northern Railway . . . 658
By A. I. TOTTEN and H. C. HUTCHINSON

The Davis Bridge Power Plant Development of the New England Power Company . 665
By E. B. COLLINS and H. R. WILSON

Internal Combustion Electric Locomotives . . . 673
By HERMANN LEMP

The Design of Small High-reactance Transformers . . . 682
By R. H. CHADWICK and D. W. MERCHANT

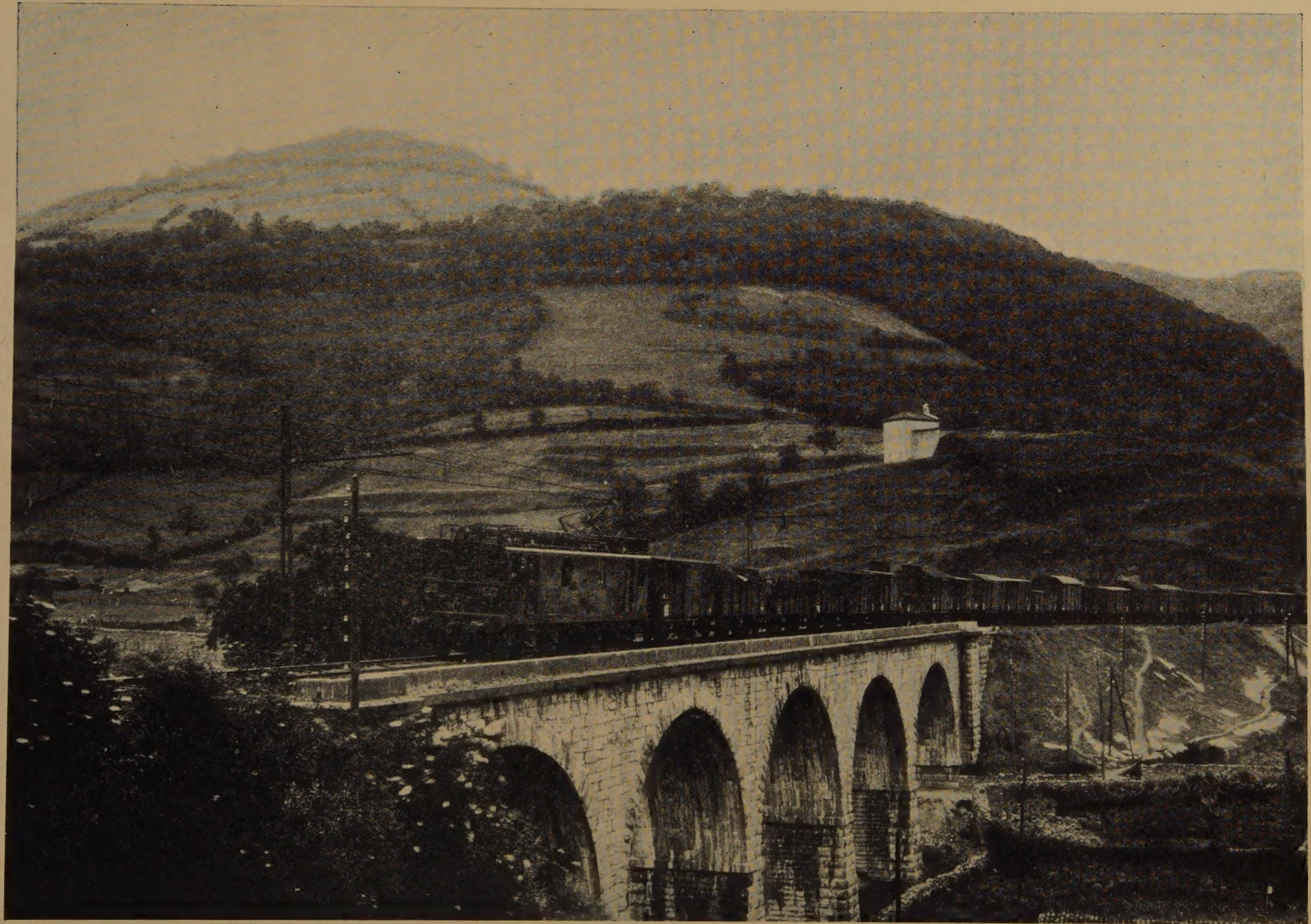
A Reminiscence of Steinmetz . . . 686
By E. C. SANDERS

Electric Arc Welding on the Steam Locomotive . . . 687
By W. M. B. BRADY

Studies in the Projection of Light. Part XIII . . . 698
By FRANK BENFORD

Recent Developments in Alternating-current Temperature Indicators for Transformers 706
By V. M. MONTSINGER

Library Section . . . 708



One of the First Photographs of the Recently Electrified Section of the Spanish Northern Railway, Taken in the Vicinity of Pola de Lena. The freight train is being hauled in the direction of load and grade by one of the 3000-volt, 90-ton, direct-current locomotives described in the article on page 658

GENERAL ELECTRIC REVIEW

CHARLES PROTEUS STEINMETZ A TRIBUTE

A year has slipped by since the October morning when the gentle, democratic spirit of Dr. Steinmetz passed from this life. We all realized, once the first shock was over, that a personality of rare charm, as well as a mentality of vast power, had gone from among us.

Folk who had seen Dr. Steinmetz only at a distance were always somewhat over-awed. They were conscious of the proximity of a giant, whose impression was all the more overwhelming if they chanced to be laymen and therefore found that to them the realm in which he wrought was a region of mystery. But those to whom was given the privilege of associating with him soon felt their awe dissolve into admiration and from that expand instinctively into the deepest fraternal regard.

It could not have been otherwise, once a person had become really acquainted with the lovable qualities of his personality; had returned the gaze of those quiet, placid, mildly eager eyes; and had listened to the contagious friendliness of that whole-hearted laugh. One came away from a meeting with Dr. Steinmetz feeling that he had discovered an ideal doctor of science—a mind keen beyond any surface indications, yet perfectly poised and capable of securing a rich store of calm enjoyment out of life.

What some people might call the hand of God, and others would term the destiny of life, seemed to direct Dr. Steinmetz's activities. It was given to him to do much for his fellowmen—which was his true life ideal. But the way in which he did this was not the way he himself would have chosen. His way would have been by a re-shaping of social conditions. The way that destiny held out to him was by the unraveling of problems in electrical science. That was how he was pre-eminently fitted to serve his race; and it gave him fascinating employment, coupled with endless distinction.

A warm, human personality, a brilliant, powerful intellect, a wise heart, all going to make up an extraordinary career in which a wisdom beyond his own enabled him to be of vast benefit to the world—yet not quite in his own way. J. W. H.

GAS AND OIL ELECTRIC CARS AND LOCOMOTIVES

The development of the gas-electric car several years ago was a pioneer achievement. No engines suitable for the purpose had been produced by gas-engine manufacturers; and therefore to build the cars the electrical manufacturer had to assume the task of developing a satisfactory prime mover in addition to solving the many problems of adapting electric generators, motors, and control to this very special application.

The 88 gas-electric cars which have been placed in service to date, most of which are still operating, have established excellent records. Their fulfillment of the dual requisites of economy and reliability has never been approached by any other type of self-propelled unit in like service.

It was but natural therefore that these qualifications should lead to the application of this superior type of motive power to locomotives. The latest development—the oil-electric locomotive—has now been made possible by the advent of light-weight, comparatively high-speed, oil engines that possess the inherent features of economy and reliability hitherto obtainable only in large engines of this type.

The utility of the foregoing varieties of equipment lies in furnishing transportation at low cost where physical conditions or investment charges prohibit standard electrification. For example, passenger traffic on branch lines is ably served by gas-electric cars at a fuel and labor cost so low as to be unapproachable by steam operation. The same is true of gas-electric and oil-electric locomotives in industrial haulage and railroad switching. Even on electrified roads they will undoubtedly soon find extensive use in yards where it is expensive or undesirable to install overhead (there are yards having as much as 200 miles of track).

But these calibres of service are by no means the limit to this type of motive power. Since electricity is used to couple the prime mover to the wheels, more powerful tractive units can readily be constructed by employing more than one power plant in the cab and correspondingly increasing the motor capacity.

Steinmetz in Fullerton Hall

By Tyler Gaskill Price

Associate Member, American Institute of Electrical Engineers

Ordinarily, an editor cannot expect that every one of his readers will be interested in any one article. Here is an exception; in fact it is more than an exception, for the interest it develops cannot fail to result in gratitude to Mr. Price of Chicago for so ably recording in type an accurate portrayal of Dr. Steinmetz on the lecture platform and for weaving into the picture those fascinating peculiarities of the Doctor and those lovable characteristics that so endeared him to us. Mr. Price has made this contribution to our columns as a sort of memorial on the occasion of the first anniversary of the Doctor's death.—Editor.

The meetings were usually held about mid-October of each year in Fullerton Hall in the Art Institute, Chicago. Long before the hour appointed the seats and standing room of the steeple sloping amphitheater would be packed. And up to the time when the speaker of the evening, who invariably "needed no introduction," was introduced there would arise in the old hall the low, continuous hum of anticipated enjoyment.

Here and there, sparsely scattered, were women. But mainly these assemblages were composed of scientists, students, college professors, and instructors; serious-minded searchers after truth who had foregathered there that a few grains of knowledge might be added to their tiny store. For these meetings were held under the auspices of the Western Society of Engineers and the American Institute of Electrical Engineers and the speaker of the evening was usually Dr. Steinmetz.

He used to smile and bow in acknowledgment of the applause which burst forth as he mounted the low stage and ambled to the speaker's desk and chair. He used to drag the chair a little apart from the desk and turn it so that he might kneel on the seat and rest his elbows and much of his weight on the back. From this position he would peer about the audience, making informal gestures of recognition to those favored ones whom he knew. His preliminaries were always humorous and leisurely without being patently deliberate.

"Ladies and gentlemen—" the Doctor would begin, and then with that infinitesimal pause which endeared him to us, he would add, "and electrical engineers." How characteristic that was of him! Ladies and gentlemen—and electrical engineers. "The subject under discussion this evening is lightning. Lightning is something of which we know very little, so I may tell you quite a lot about it without fear of contradiction." Always that genial drollery, always that accurate reckoning of his own knowledge as compared to what was still to be learned, always the impression that he spoke to men and women who knew as much as he did. The printed words give his language but they fail to convey the spirit of his utterance.

"But we do know," Dr. Steinmetz would continue, "that when lightning strikes an electric circuit directly it destroys it. The only procedure in such a case is to trust in Providence and repair such damage as has been done." The juxtaposition of ideas was humorous but his tone gave his auditors the impression that the Doctor carried about within him a deep and abiding faith.

As he spoke he wrought a miracle, and year after year he repeated it, a psychological miracle upon his audience. We lost consciousness of the small body and its strangely shifting postures about the chair. We forgot that his speech was not like that of other men. In our eagerness we overlooked the momentary interruptions when the Doctor would break off in the midst of a sentence to take a drink, and, climbing back upon his chair, would resume his discourse, not at the sentence but at the very word at which he had interrupted himself. We became conscious only of the clear out-pourings of that beautifully working mind and the exquisite swiftness and precision of his imagination.

He used to speak without notes but his diction was smoothly coherent. Now and again he would perform mind-conjurings with astronomical numbers that left us gasping. His logic was direct and so naive that we were not infrequently irritated by our impotence to reach the conclusions which he attained so deftly.

For about an hour the Doctor would pour forth his conceptions of lightning, or high-voltage transmission, or water-power resources with an easy continuity of thought and an accuracy of reasoning that the veriest novice might understand. We, followers, rank-and-filers, sat spellbound by his words, even as Thomas Burke sat bound by the spell of De Pachman's music.

With the applause which followed like a hattering avalanche, the miracle disappeared. We knew again that we were in Fullerton Hall in Chicago, and once more we saw the huge glass central chandelier and names of the great composers embossed upon the walls. Again, we looked upon a diminutive, umbling figure that we loved.

But the end of the lecture did not mark the end of the enjoyment. There was still the informal discussion which followed close on the heels of the main discourse. Then we would hear experiences by many of the men who had there assembled to learn a little for themselves and to contribute a little to the knowledge of the profession if they might. There would be stories of transmission lines blown down by fearful hurricanes, of hydro-electric stations wrecked and buried by snow-slides and rock-slides, of deep-singing rapids in the West that might one day be silenced to do the work of man.

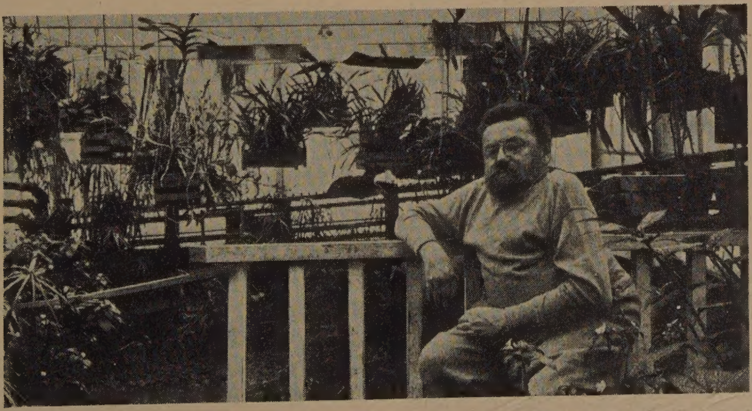
To all these accounts the Doctor listened as though the speakers were eminent authorities and he the learner. Sometimes he would shake his head a little sadly and say, "No, I have never seen that, I cannot tell. I am sorry." Or again he would bob his head eagerly and smile and exclaim, "Yes, yes, I have seen that many times. It is true."—and off he would go, his eyes dancing with enthusiasm and for a little space the miracle would be resumed.

But mostly the discussions were in the form of questions by the audience and answers by Dr. Steinmetz. Some questions were pertinent, short and to the point, and some were ramblingly verbose and inconsequential, put mainly, one would judge, that the inquirer might hear himself talk, and some were downright idiotic. It mattered not. The Doctor listened intently and answered courteously without regard to personalities or the reasonableness of the question.

Only once in a long series of years did his answer suggest doubt of his questioner's veracity and then he was so adroitly comic that we chortled—audibly.

An engineer of a western power company described a phenomenon which he said occurred daily in the vicinity of a certain hydro-electric station. The station operator had seen it frequently. "You say," stated the Doctor hesitantly, "that this ball of fire appeared about two o'clock every afternoon and that it traversed, in mid-air, the entire length of the canyon in full view of the station operator?" The defendant nodded. "Well," said Dr. Steinmetz slowly, "I have seen such phenomena happen, but never frequently, nor twice in the same place. I think it would help to clear things up if we could know what the operator used to eat for luncheon."

We shall miss that humor in the years to come. We shall miss the kindly spirit and the great, swift-glowing thoughts with which he used to kindle our imaginations. The meetings will still be held in Fullerton Hall about mid-October of each year. They will be well attended, for there will be distinguished speakers on the platform. But the day of miracles is past.



Dr. Steinmetz in His Conservatory Where He Took Great Pleasure in Studying Plants, Particularly Those of Tropical Variety

Extinction of Fires in Generators by Means of Carbon Dioxide

By Charles L. Jones

Industrial Fellow, Mellon Institute of Industrial Research,
University of Pittsburgh

Because of the great care exercised in the design and operation of generators, they do not often take fire though combustible material enters into their construction and they run at moderately high temperatures. Nevertheless, the possibility of fire occurring calls for some effective means for its extinction. Opinions differ as to what is the best means and consequently several fire-extinguishing mediums have found use. Mr. Jones, who is an advocate of carbon dioxide, reports in the following article a series of experiments made with this gas at the Mellon Institute of Industrial Research. The tests were conducted on pieces of generator coil. The effects of windage, gas composition, air temperature, copper temperature, and insulating materials are discussed. The author's deductions as to the utility of carbon dioxide for extinguishing fires in generators should be of interest to every one concerned with the design and operation of these machines.—Editor.

If it were necessary to condemn for test a single large generator in order to develop a thoroughly satisfactory fire-extinction system for generators, and even though the cost of the condemned machine might soon be recovered through actual fires avoided or extinguished, it is very doubtful whether such a system would ever be designed. However, a fire-extinction system of merit has recently become available, thanks to the development of apparatus for extinguishing fires in the holds of vessels; and it has been the writer's purpose to study the conditions under which fire takes place in generators, and to determine the applicability of this system to the generator problem.[1]

Evolution of Fire Extinction for Generators

In the past, progress in the power-generation field toward freedom from fire hazard has taken two principal directions: first, changes in the materials and mechanical construction of the machines; and second, the more recent development of closed-circuit ventilating systems that, in themselves, greatly reduce the fire hazard.

Still more recently a third type of development has come into being; namely, provision whereby an atmosphere non-supportive of combustion is either maintained in the ventilating system or produced in case of fire, so that fire originating through breakdown or any other cause cannot be propagated around the end windings and will be extinguished or at least localized in destructive effect.

The ideas of electrical engineers on fire prevention and extinction have advanced with the development of the electrical industry, but further progress is to be expected and must be made. With the older types of generators, it was considered necessary to have the entire machine as open as possible to assist cooling. Often a fire in one of these machines completely destroyed the windings. While at other times only a part of the windings were burned, the remainder would be water-soaked and the neighborhood covered with heavy black soot. The localization of fire in such machines, which sometimes occurred fortuitously, could not be depended upon.

The development of the carbon-tetrachloride extinguisher was a step forward in handling fires in open machines, but was conceded to be far from ideal in its effects. By degrees generators were being constructed more enclosed, until the completely enclosed generator with open-circuit ventilation was finally introduced. These machines were, however, and are still, far from gas-tight, and not many years ago the leakage was properly considered to prohibit the use of any gaseous fire-extinction medium. This view was certainly justified at the time.[2]

In order to obtain freedom from dust, noise prevention, fire prevention, more positive control of cooling, and more recently heat conservation, the tendency toward completely enclosed and short-circuited ventilating systems continues, but actual gas-tightness has never yet been aimed at to the writer's knowledge. The most recent turbine-generators are closed so far as noise is concerned, and are commercially gas-tight from the standpoint of ventilation and heat loss. They are, however, not nearly as gas-tight as they could easily be made at moderate expense, if this object were held definitely in view. To show the extent of this leakage the following instance is cited: In experimenting with a 20,000-kw. machine with a 3300-cu. ft. closed-circuit ventilating system, a leakage of over 200 cu. ft. per minute was indicated by the changes in gas composition. No alteration was made in the manufacturer's standard design, as the generator lagging was considered "reasonably tight."[3] This case is not held up as a horrible example; but it is suggested that a few dollars' worth of intensive leakage study and shellacked gaskets, with attention to the closure of dampers or relief doors, would materially reduce this figure and would be amply repaid in case of fire. Of course a practical system must be effective with generator lagging as it is now.

---

[1] Reference is made to the "Lux" system, a marine fire-extinction apparatus introduced originally in Sweden, whereby liquefied carbon dioxide can be released at very high rates of flow from high-pressure cylinders of standard dimensions without stoppage or freezing.

[2] Lamme, *Journal A.S.M.E.*, *36* (1914), 135.

Present Status of Generator Fire Extinction

As recently as 1919, the Subcommittee on Generators of the N.E.L.A. reported on prevalent views and operating practice with regard to water, steam and carbon-tetrachloride fire extinction, and stated: "The possibilities of liquid carbon dioxide or other non-combustible gases or liquids have also been discussed, but no advocates of these materials have been found.[4]

Since that time two companies have pioneered in the development and installation of carbon-dioxide fire-extinction systems, and such systems are now installed in the Cahokia and Ashley St. stations of the Union Electric Light and Power Co. of St. Louis, and the South Meadow station of the Hartford Electric Light Co. These systems have been described fully elsewhere[5] and need not be discussed in detail here. The writer's work has been directed toward evaluating the merits of the system, and assisting in the improvement and cheapening of the apparatus used for storing and discharging the carbon dioxide.

A half-dozen or more additional operating companies are now considering carbon-dioxide fire extinction in connection with present or projected alternators, and the work described in this article has been carried out to afford a further basis for the rational design of such installations.

Schools of Thought Among Engineers

There are several distinct schools of thought among electrical engineers with regard to the probable behavior of fire in a closed machine of the most recent type and the best means of dealing with such fires.

First: Many engineers make the statement that, with closed-circuit ventilation of the most modern type, any fire in the generator would quickly extinguish itself with its own products of combustion. This view is a natural one to take, and has sufficient truth to be given ready acceptance unless a careful analysis is made of the conditions. Based on the writer's experiments, and assuming a six-to-one carbon-hydrogen ratio in the insulating compound, with 25 per cent oxygen depletion to extinguish flame, it has been found that a generator with a total volume of 2000 cu. ft. in the ventilating system would require the burning of about three pounds of organic insulating materials before flame would be extinguished, *assuming no leakage.* However, the important question is not "how much material will burn?" but "how much insulation will be damaged, and how much of the machine will have to be re-wound?"

Viewed from this angle, the case presents a different aspect. The three pounds of insulation consumed would not likely come from a single end-winding. On the contrary, flame spreads over the surface of the hot windings with great rapidity. Three pounds of combustible compounds represent much more than three pounds of built-up insulation. Three pounds of insulating pitch would cover nine square feet of surface to a depth of $\frac{1}{16}$ in., and windings burned to this *average* depth probably would be burned so much deeper in spots and on corners as to loosen the mica and require re-winding.

Leakage also counteracts self-smothering to a serious degree. Modern closed-circuit ventilation systems often leak from two to four or more times the entire volume of the system in a half-hour period. This leakage would continue to keep the fire going at a low rate; hence it must be conceded that simply providing a commercially-tight ventilating system in accordance with present practice is a very effective way of putting a fire *almost* out, but will not limit the damage to the point of origin of the fire.

The writer believes that the self-smothering feature can be relied upon only to decrease the rate of combustion and to minimize the nuisance connected with the after-effects of fire. If all conditions favor the occurrence of fire originating with great explosive violence it is theoretically possible for self-smothering to take place before the fire has spread far from the point of origin. This would require the instantaneous volatilization of several pounds of combustible gases from the insulating material near a single point, which is extremely unlikely.

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[3] Soren, "Extinguishing Generator Fires with CO^2," *Electrical World, 80,* (1922) 1089-1091.

[4] *Power, 49* (1919), 950-1.

[5] *Electrical World, 80* (1922), 165-7; *idem,* 1089-91.

It is much cheaper to obtain inert gas from an outside reservoir in which the supply is easily replaced than to procure it by the combustion of a few pounds of insulating material, which may cost a comparatively large sum to replace by re-winding. If the damage can thus be localized in the coils where it originates, the fire-extinction system has done all that should be expected of it.

Second: Another group of engineers favors the use of water. It cannot be denied that water, liberally used, has no equal and not even a rival for cooling and quenching effect when large amounts of heat are to be dissipated. If its effects on electrical phenomena are ignored, water stands first among all fire extinguishers. The joys of drying-out generators, however, are too well-known to many operating men to need rehearsing here, and it is believed that the advocates of water are themselves thoroughly familiar with its limitations.

It is interesting to note that both water rings and carbon-dioxide equipment have been provided at the new Cahokia station in St. Louis. This installation makes water available as a last resort, while the gas system may first be operated automatically or manually whether the load is on or off the machine. Prevailing opinion does not favor the application of water while the machine is under load. The time thus gained by the inert-gas system is one of its greatest advantages, and is possessed by no other system.

The writer believes that water rings will never be called upon where a properly designed carbon-dioxide extinction system is installed, but recognizes the value of water, and the logic of holding water rings in reserve until other means have proved their reliability in actual service.

Third: Still another group believes in steam. Steam smothering has been practiced for many years in extinguishing fires in the holds of ships. Steam-smothering pipes in the cargo holds of all steam vessels are required by Federal statutes and by the U. S. Steamboat Inspection Service. The writer has discussed the relative merits of steam and inert gases for marine fires elsewhere[6] and ventures to suggest that the results of experience in the marine fire-extinction field will prove interesting to students of analogous electrical-fire problems.

The action of steam and inert gases is similar in some respects, because the purpose in each instance is to exclude oxygen rather than to cool or quench the burning material quickly below the ignition point. The successful smothering of generator fires with steam is therefore a forecast of more successful smothering with carbon dioxide.

In marine fires one of the principal advantages possessed by steam is the practically unlimited supply available on steam vessels. This consideration in the past, together with the fixed policy of marine underwriters in not giving specific rate reductions for the installation of safety devices, has tended to confine carbon-dioxide fire-extinction systems to the Diesel-driven vessels of the few owners who protect their ships and their clients beyond the minimum legal requirements. Since the volumes of generator systems are small compared to the holds of vessels, an adequate supply of gas can be provided at small cost, and the problem of sufficiency of supply is only a technical and not an economic consideration.

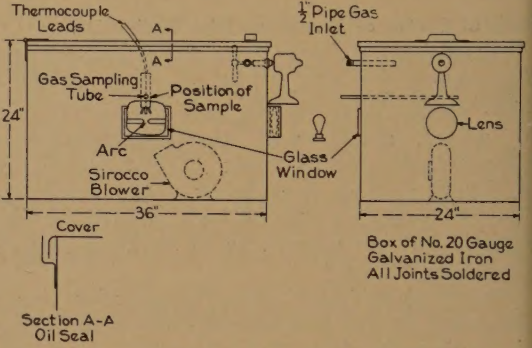

Fig. 1. Diagram of Experimental Set-up for Testing the Fire Extinguishing Properties of Carbon Dioxide

The principal difference to be considered, therefore, is the difference in the two smothering materials.

The two important differences between carbon dioxide and steam are in the boiling-points and electrical properties. Carbon dioxide is gaseous at ordinary temperatures, and is injected into the generator housing somewhat below room temperature in the low-pressure system, and at 100 deg. below zero Fahrenheit in the high-pressure system. In either case proper design will avoid severe thermal shock. Steam, on the other hand, cannot be employed below the boiling-point of water, and some companies use high-pressure superheated steam. It is claimed that in the case of a fire of the surface or "static" type, steam can be introduced for a short period without the necessity of subsequently drying-out the generator; but the generators were not designed to run in an atmosphere of superheated steam, and the time of application of high-temperature steam is strictly limited. It must be recalled that the safe maximum "hot-spot" copper temperature greatly exceeds safe temperature for the outer wrappings of the coils, since a fairly high copper temperature may occur in service while the wrapping is comparatively cool.

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[6] *Proc. Nat. Safety Council,* 1923, 542-8; *The Weekly Underwriter,* October 13, 1923, and October 20, 1923.

The case against steam may be summed up by saying that steam in a generator is potentially and actually water; that the generator must be electrically dead before it can be safely applied; and that its high temperature makes peace of mind impossible when releasing it into a generator.

Fourth: While carbon-tetrachloride has been used on generator fires, it is not strongly recommended for fires in the enclosed types, being more often used on the older open machines. Carbon-tetrachloride does not agree well with insulating materials, metals, or men. Its objectionable features make its value as a fire extinguisher a secondary consideration in this particular application, and it is deemed unnecessary to re-state its disadvantages. Even as a smothering agent, it is markedly inferior to carbon dioxide in cooling effect, ease of volatilization, and volume of vapor produced per pound, while it is more expensive.

Fifth: There is a small but increasing number of engineers who favor the application of inert gases, realizing that in inert gas lies the only hope of a fire extinguisher that will be harmless in itself. The growth of this group depends upon the availability of appliances of reasonable cost for dependably discharging carbon dioxide into generators.

The writer's work shows conclusively that discharging 25 per cent by volume of carbon dioxide into the atmosphere of a generator ventilating system will promptly extinguish all flame, lower the temperature, and confine the damage to the coils in which fire originated.

EXPERIMENTAL INVESTIGATION

It was considered necessary to make a study of the combustion of insulating materials in order to know what percentages of carbon dioxide must be provided to prevent the spread of fire in such materials. At the start it was realized that many variables, some of which are unknown, affect the progress of fire, and that some of the niceties that are possible in determining the combustibility of gases would have to be sacrificed to secure a significant test procedure.

Apparatus

The apparatus used is shown diagrammatically in Fig. 1. It consists of a galvanized iron box insulated with asbestos paper, in which are placed an arc for heating and igniting the specimen, means for supporting the specimen over the arc, space heaters for controlling the air temperature in the box, and a blower to produce a windage effect by circulating the gas in the box.[7] The blower, a Sirocco with 3½-in. discharge, is placed on the bottom of the box so as to circulate the atmosphere. The outlet of the blower is 12 in. from the center of the test piece, producing a wind velocity at the test piece of 18 ft. per second.

The test pieces were six-inch lengths of generator coil, furnished by the General Electric Co. It should be remembered in this connection that the baking operation alters the flash point and fire hazard of the coils, so that tests made by means of candles, pieces of unbaked insulating tape containing solvents, etc., are not reliable.

The samples tested included some containing 54 wires and some containing 72 wires, of both the 6600-volt composite-type insulation and the 13,200-volt all-mica insulation. A thermo-couple was placed in a hole drilled from one end to the center of the sample, and the readings were recorded as "copper temperature." The other end of each sample was then stripped for about one inch from the end, and the wires "fanned out" to present the maximum surface to the arc flame. The bare copper thus exposed to the arc served to conduct heat through the interior of the test piece. This heating "from the inside out" produces a condition roughly similar to the service condition, in which the insulating compounds may be distilled by the hot copper. Some of these samples are shown in Fig. 2.

Fig. 3 shows the general arrangement of the apparatus. In this, a cylinder *1* contains carbon dioxide. Carbon dioxide and air were fed through the capillary flow meters *2* and *3*, which measure the pressure drop across a capillary tube, and through the mixing tube

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[7] It is recognized that windage is not constant throughout a generator. From an experimental standpoint, however, it was desired to determine the effect of a definite windage at the seat of the fire. The small desk fan shown in the drawing was used simply to insure thorough mixing of the gases in the box before starting an experiment.

4 into box *6*. Through an inspection window *8* the air thermometer may be seen. Strong illumination from light *5* was focused on the test piece by means of a lens to permit close inspection of its behavior independently of the arc illumination.

The gas sample tube *7* leads from immediately above the test piece. The box is closed by fitting the cover into an oil-seal groove around the top. The leakage is sufficient, however, to vent the gas introduced, so that the gas composition in box *6* may be maintained constant by controlling the relative rates of air and carbon-dioxide flow through tube *4*. The composition of this gas mixture was determined by Water-Orsat analysis, which was considered sufficiently accurate.

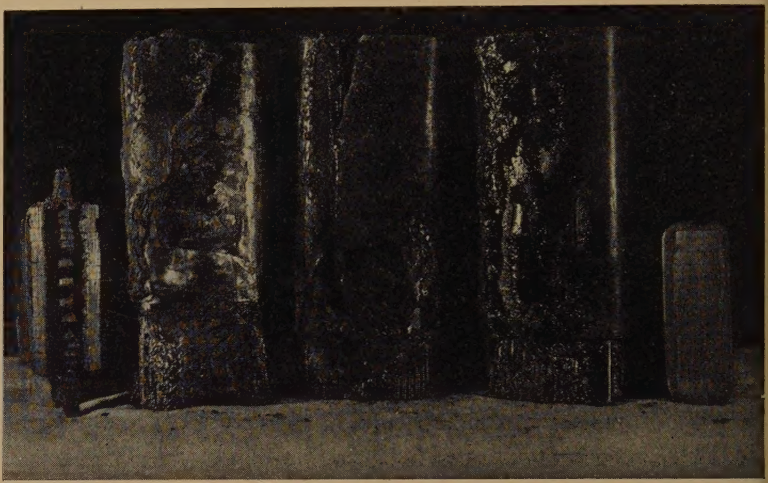

Fig. 2. Samples of Generator Coil After Testing

Method of Procedure

In making tests the gas composition was first adjusted, and the air temperature brought to the desired point. The arc was then started and the behavior of the sample observed. The "copper temperature" of the sample was noted at regular intervals, while the gas composition and wind velocity were sometimes changed during the course of test in order to extinguish the flame.

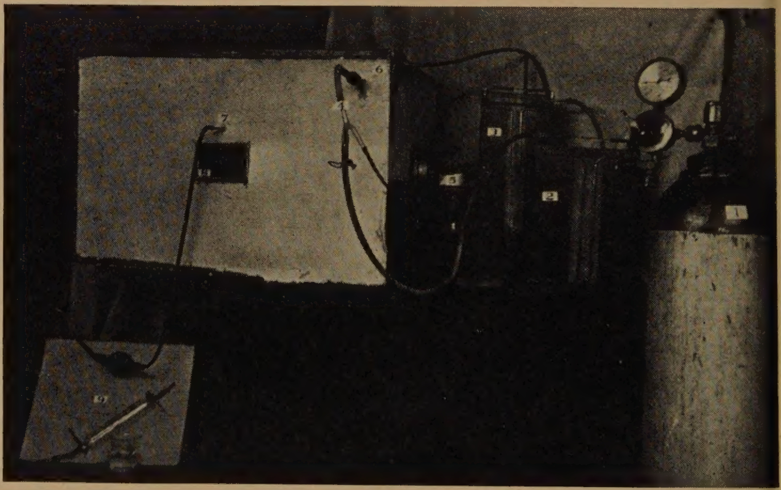

Fig. 3. Arrangement of Apparatus Employed in Making the Tests

Discussion of Results

The effect of the gas composition, wind velocity, air temperature, insulating material, and copper temperature in the experiments has been considered. About a dozen experiments were performed under different conditions, and the data permit drawing conclusions with regard to some of the variables.

The results of a typical experiment, in which the effect of windage was studied, are shown in Fig. 4. In this experiment the blower was turned on at intervals. The oxygen content throughout the experiment was kept above 20.5 per cent by passing in fresh air. The kinks in the copper-temperature curve are due to the breaking and re-establishment of the arc each time the blower was started. Under the conditions of this experiment, the flame was extinguished in normal air up to a copper temperature of 500 deg. C., and an air temperature of 100 deg. C., by simply increasing the wind velocity to 18 ft. per second.[8] While this operation extinguished the flame, it fanned the incandescent carbon, so that the carbonized portions of the insulation were kept glowing down to 240 deg. C., copper temperature. This glowing would no doubt have continued even at lower copper temperature, but on turning off the blower the glowing material immediately blackened and cooled. In 20 sec. it could not be re-ignited by fanning.

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[8] This wind velocity was determined for a definite setting of the Sirocco blower, by holding an anemometer in the same position as the sample.

While the experiments on carbon-dioxide extinction do not lend themselves to graphical treatment, the general procedure was similar, except that the ratio of CO_2 to air was varied, and the gas analysis was made when the flame was extinguished.

The close visual observation of the behavior of the test pieces is of considerable importance. This behavior must be interpreted in the light of the familiar chemical and physical changes that take place. Since the tests do not yield results suitable for presentation in tabular form, the experimental results have been incorporated in the following summary:

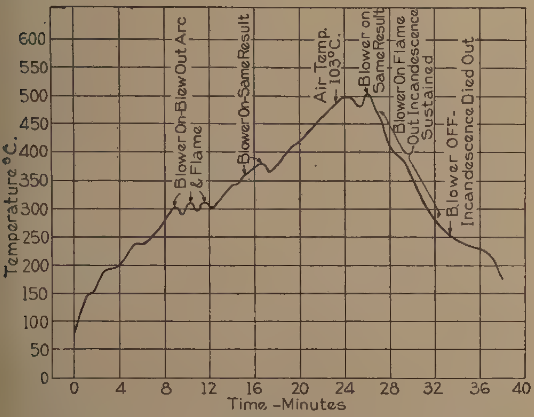

Fig. 4. Curve of Temperature in Center of Test Piece *vs.* Time, in Normal Air at 103 Deg. C. Max.

First: The flash-points of insulating materials are so high as to make tests on cold materials in cold air meaningless. The fire hazard under these conditions is very small.

Second: Samples heated by the method of these experiments take fire in normal air and no windage at a copper temperature, as here measured, of 250 to 300 deg. C.

Third: This temperature, when interpreted in the light of the experimental procedure, does not represent a true flash point, but is simply the temperature at which the insulating pitch or binder "cooks out" and starts to decompose, furnishing sufficient vapor to be ignited by the arc, provided the surrounding atmosphere contains 20.5 per cent or more oxygen and the wind velocity is favorable. It must be remembered that the samples were heated more uniformly than are the coils in actual service, for the air temperature was above service temperatures, and hence the heat gradient from the center of the coil to the outside wrapping was not so great. The outside insulation temperature was no doubt higher, soon after ignition, than the indicated copper temperature, and this is the condition that obtains *after* a fire starts in a generator. The temperature of the wrapper after the starting of a fire is hotter than would be found in service under any conditions.[9] The continuous presence of an arc, as a source of ignition below the test piece, also modifies the conditions. It was the aim to make all these conditions more drastic than would probably be met in service, so that methods of extinction worked out on the basis of the experiments would have a factor of safety in their application to generators under practical conditions.

Fourth: The fire hazard, from the standpoint of spreading fire throughout the machine from a source of ignition, is identical for all-mica and for composite-type insulation. This should not be confused with the superior service characteristics, or fire-resistive merits of all-mica insulation, which have no effect on the spreading of a fire once started along the exposed surfaces of coils.

Fifth: The phenomenon brought about by varying the gas composition is not a simple one and it includes several effects. The mixture contains oxygen, nitrogen, carbon dioxide, and combustible gases from the insulation. The effect of adding carbon dioxide without changing the oxygen content is to narrow the explosive limits of the combustible gases. When the upper and lower explosive limits meet, there is no explosive range and flame cannot be propagated. It is thus possible to extinguish flame by substituting carbon dioxide for the nitrogen of the air without changing the oxygen content. The reduction of the oxygen content will independently produce a similar effect, and this reduction in turn depends upon two factors: first, the oxygen abstracted by the fire; and second, the lowering in oxygen caused by diluting the air with carbon dioxide. In a general way, the behavior of the system is similar to the behavior of mixtures of methane, oxygen, carbon dioxide, and nitrogen. Clement[10] has made a thorough experimental study of this system, and those who are interested in a detailed analysis of the phenomena involved should refer to his original paper.

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[9] Cf. Lamme, *Transactions of the A.I.E.E.*, *35* (1916), 1471-88.

[10] Clement, J. K., "The Influence of Inert Gases on Inflammable Gaseous Mixtures." *U. S. Bureau of Mines*, Tech. Paper 43 (1913).

The writer's earlier experiments on mica tape and on samples at low copper temperatures indicated that 10 per cent carbon dioxide added to the air would make flame in these materials impossible.[11] In these experiments the ratio of burning material to the air supply was such that considerable oxygen depletion took place due to the fire. The amount of the oxygen depletion resulting from the fire is proportional to the insulation consumed, and the object of the carbon-dioxide system is to keep this figure as near to zero as possible. In later experiments, the copper temperature was raised to 400 and 500 deg. C., the air temperature to 100 deg. C., and an attempt was made to furnish such a large supply of the air and CO_2 mixture that the effect of diluting with carbon dioxide would be divorced from the effect of the fire taking oxygen from the air. This ideal was not realized as some oxygen depletion (one to two per cent) was always noted, the oxygen being 19 to 20 per cent of the combined oxygen and nitrogen in the best experiments, and the added carbon dioxide from 17.5 to 20 per cent of the gas sample taken at the moment when the flame was extinguished. The percentage of oxygen in the sample was thus 15.0 to 16.5 per cent. Under these conditions it was found impossible for the flame to propagate.

Clement's research provides a relationship for calculating these results on a basis of no oxygen depletion, and based on that work, together with the writer's experimental results, it is concluded that flame can not be propagated in an atmosphere of 75 per cent normal air (containing approximately 21 per cent oxygen) and 25 per cent carbon dioxide; using an arc as the source of ignition; vapors from overheated insulating pitch as the combustible; and any air temperature, copper temperature, and windage within the scope of these experiments.

This figure is suggested as a conservative basis for estimating carbon-dioxide fire-extinction systems. It should be noted that the conditions of these experiments err on the side of conservatism, and much smaller percentages will be sufficient to extinguish the fire, if:

(a) The air and copper temperatures at the origin of a fire are lower than the temperatures of the experiment.

(b) The fire originates in a part of the machine directly subject to a high windage. In this case, however, any glowing carbon will be fanned until the machine is stopped, and a satisfactory gas composition will then be necessary to prevent the outbreak and spread of flame.

(c) The fire causes a further reduction in oxygen percentage beyond that caused by dilution with carbon dioxide.

These considerations have the effect of incidental factors of safety in the operation of the system.

The actual amount of gas storage to be provided depends largely upon the leakage conditions of the generator setting and ventilating system, and should be sufficient to maintain an extinctive atmosphere in the generator for a definite period of time. It is suggested that this period should correspond to the time required to bring the generator to a full stop, plus an allowance of a few minutes for a possible investigation of the trouble before definite steps are taken to stop the machine.

With tight generators of the later types, the gas storage to be provided will correspond to at least 50 per cent of the volume of the ventilating system, or approximately 50 lb. of carbon dioxide per 900 cu. ft. Further refinements in making ventilating systems gas-tight may cut this figure considerably, but in the present state of construction leakage tests should be made in each instance to determine the excess gas required to compensate for leakage.

Sixth: The data presented in the foregoing indicate that the addition of 25 per cent carbon dioxide to the ventilating air will completely extinguish surface fires not involving incandescent carbon. This may be done without taking the machine off the line, and the generator may be continued in service until it is convenient to inspect it. Fires from internal short-circuit, on the other hand, necessitate a shut-down, and involve incandescent carbon as well as flame. The additional complications introduced in such cases are considered in the following paragraphs.

Seventh: The effect of high wind velocity is to extinguish flame when the wind velocity exceeds the rate of propagation of flame. The critical wind velocity to extinguish flame depends upon the temperature, the composition of the combustible, and the gas composition. These quantitative relationships were not investigated, but it was found that a wind velocity of 18 ft. per second will extinguish flame in insulation, such as was furnished by the General Electric Company, up to a copper temperature of 500 deg. C., when the air temperature is 100 deg. C., with the air containing not less than 20.5 per cent oxygen. This was considered such convincing evidence of the effect of wind velocity that all other tests were made in still air, with only the natural draught due to the fire. It may therefore be assumed that a gas composition which will extinguish flame in still air will be even more effective at a high wind velocity.

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[11] Cf. Soren, *Electrical World, 80* (1922), 1089-91.

Windage in generator air passages exceeds the foregoing figure many times, and this explains why completely burned out machines usually show the effects of flame spreading around the end turns, where the windage is not so high, and where eddies favor low-windage conditions at some points. It therefore appears that the primary function of the inert-gas system is to protect the end turns, where windage conditions do not insure the "fanning out" of flame.

Eighth: The effect of a high wind velocity on incandescent carbon is just the opposite of its effect on flame, and incandescent carbon will be fanned to a bright glow by high wind velocities, even when there is less than five per cent of residual oxygen in the gas atmosphere. The behavior of such glowing carbon depends entirely upon its temperature, and it can be extinguished only by cooling below the ignition temperature. This may be readily accomplished by stopping the machine and allowing it to remain in still air, provided the re-kindling of flame is prevented by introducing carbon dioxide.

It is impossible to generalize on the behavior of incandescent carbon, which will, in service, depend upon the heat-dissipation characteristics of the particular coils that have been carbonized at the start of a fire. It was determined by experiment that the combustion of glowing incandescent carbon in the wrapping of a 6600-volt composite insulated coil will not travel more than one foot in 30 min. at a wind velocity of 18 ft. per sec. If, therefore, flame can be immediately extinguished by excluding air and introducing inert gas, the fanning of glowing carbon will not be able to spread the damage to any great extent before the machine can be stopped and the wind velocity reduced to zero. Any glowing spots will then die out in a short time.

Ninth: The behavior of flame is very different from that of glowing carbon. Flame is the medium of rapid communication of fire from coil to coil, and not glowing carbon. An inert-gas system, which makes flame impossible at any windage until the danger is past or the generator stopped, therefore does all that should be expected of it. By the time windage has been stopped, the glowing spots should have died out, because an effective automatically operated carbon-dioxide system should smother flame so quickly that the mass of glowing carbon will be small; in other words, rapid cooling of the carbon below its ignition point will follow when windage ceases to fan it.

It will thus be seen that flame is extinguished either by

(a) windage, or
(b) inert gas.

The important difference between these two means arises from the fact that windage is not uniformly high throughout the machine; and that when flame is "fanned out" by windage any incandescent carbon is only caused to glow more actively, producing additional heat for promoting a general conflagration when the windage dies down. With an inert gas, flame is put out immediately and kept out, regardless of windage, also the temperature is lowered. This will decrease the incandescence and probably put it out, especially if the machine is shut down at once, thus permitting the incandescent carbon to cool unhampered by windage.

Summary

The results obtained in these experiments do not by any means completely define the effect of all the variables on insulation fires, but they do afford a satisfactory basis for the design of inert-gas fire-extinction apparatus with reasonable certainty that fire can be controlled as predicted.

It is believed that the combustion of generator insulation has been studied in sufficient detail to feel assured that the addition of 25 per cent of carbon dioxide to the ventilating air in a generator will immediately extinguish surface fires; and in any case will make it impossible for fire damage to extend beyond its location when that concentration is established, with excellent chances that flame will be stopped even earlier in most cases. And, when incipient fires, due to excessive local temperatures, are discovered by emission of smoke, before any fire has started, the fire may be effectively prevented.

The 3000-volt Electrification of the Spanish Northern Railway

By A. I. Totten and H. C. Hutchinson

Railway Engineering Department, General Electric Company

And now another 3000-volt direct-current electrification. The selection of this system by the Spanish railway company engineers has special significance in view of the exceptionally severe traffic conditions: 71 tunnels (one nearly two miles long), 3234 ft. rise in elevation in 38.5 miles in the direction of load, sharp curves, and single-track operation. The following article describes this most recent substitution of electric locomotives for steam locomotives, the locomotives themselves, the motors, control, auxiliary equipment, substations, transformers, motor-generator sets, and overhead line construction.—Editor.

Prior to 1914 Spain received most of its coal from the British Isles, but during the late war shipments were greatly reduced and finally stopped entirely. The resulting shortage was keenly felt by all the large cities, especially Madrid. Mines were placed in operation which before had been considered unprofitable. Particularly was the output increased in the Asturias region in the Cantabrian Mountains which parallel the north coast. The amount of coal which could be shipped to the center of Spain, however, was limited by the capacity of the railways leading out of this region. In fact much of the coal was shipped north to the port of Gijon, whence it was transported by boat to other domestic ports.

The Northern Railway of Spain has a single-track line running from Gijon on the coast, south through Oviedo and Leon, and joining the main line from France to Madrid at Venta de Banos. The limiting feature of this line is the section between Ujo which is 248.9 m. (816 ft.) above sea level, and Busdongo which is just over the ridge on the southern slope of the mountains, and which is 1233 m. (4050 ft.) above sea level, a total distance of 62 km. (38.5 miles).

It is this section which is now being electrified as the initial step of an extensive program. In this distance the road goes through 71 tunnels, with an aggregate length of 27 km. (16.8 miles), most of which are on curves. The longest tunnel, La Perruca, a short distance north of Busdongo, is on tangent track and has a total length of 3071 m. (10,080 ft). The longest tunnel on the curved sections is El Orria, which is 1059 m. (3475 ft.) long and turns through about three-quarters of a complete circle.

This remarkable stretch of railway was built about 40 years ago under the direction of a prominent Spanish engineer. It is interesting to note that in Spain, as in Russia, the track gauge differs from that of neighboring countries. There it is 1675 cm. (5 ft. 6 in.), while in France and the remainder of Europe the American standard of 1435 cm. (4 ft. 8½ in.) is almost universally used.

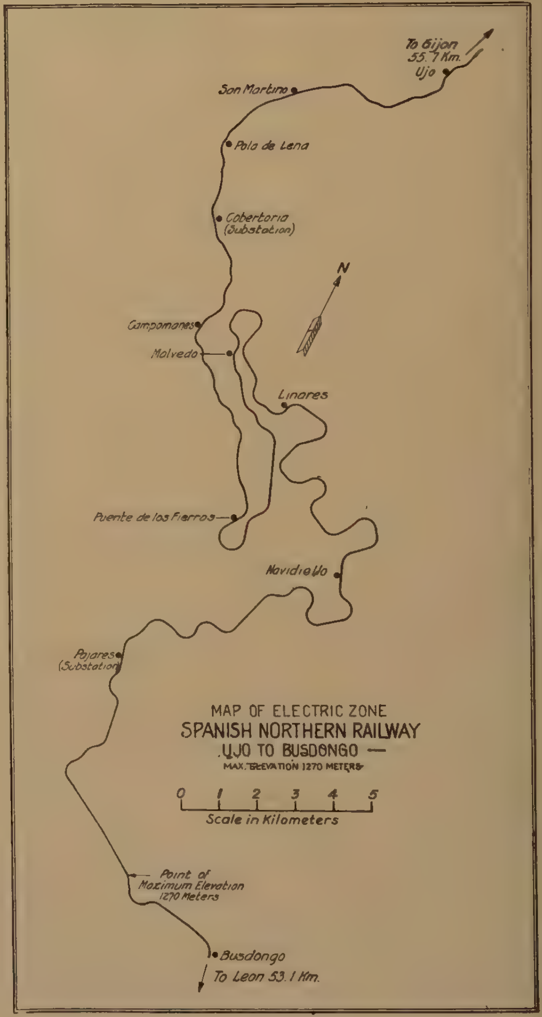

Fig. 1. Map of the 38.5-mile Electrified Section of the Railway

The initial contract for this electrification was awarded to the Sociedad Iberica de Construcciones Electricas, the Spanish representatives of the International General Electric Company, and provides for six 3000-volt locomotives, two 2-unit 3000-kw. substations, and overhead line material for the complete project. In addition to the items listed, six additional locomotives have been ordered from other manufacturers. For the present, power is purchased from the hydroelectric system of the Electra de Viesgo Company at 30,000 volts, 3 phase, 50 cycles. This energy is transmitted over the lines of the railway company to substations located at Pajares and Cobertoria.

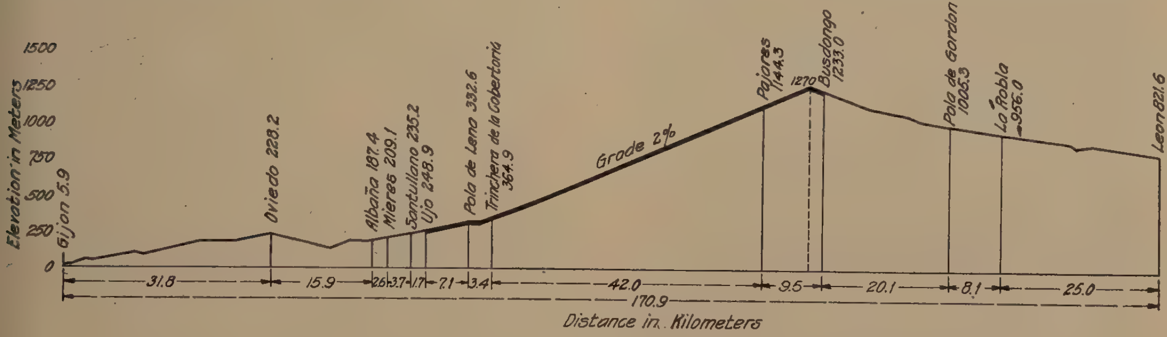

Fig. 2. Profile of the Division of the Railway Including the Electrified Section Indicated by the Heavy Line

Locomotives

The present daily schedule with steam operation consists of 12 trains in each direction. It is expected that with the substitution of 12 electric locomotives for steam power, the normal train movement can be considerably increased. This will release 28 steam locomotives for other service. The locomotives which the General Electric Company has constructed for this service are of the swivel-equalized-truck design and weigh 81.4 metric tons (89.5 short tons), all on the driving axles. With this type of locomotive the pulling stresses are transmitted through the platform of the locomotive instead of through the truck frames as is the case with the articulated type.

The cab is supported through center plates on two 3-axle trucks. Six motors geared one to each of the six driving axles give a total capacity of 1550 h.p. Hauling a 330-ton train up the two per cent grade at a speed of 35 km. per hr. requires a tractive effort of 10,000 kg. (22,000 lb). The maximum speed on level tangent track is 40 km. (24.8 miles) per hr. with a train of 1500 metric tons (1655 short tons), while the maximum emergency speed of the locomotive is 60 km. (37.2 miles) per hr.

The auxiliary apparatus and control mechanism are housed in a box-type cab which extends the full length of the locomotive. The platform, built up of structural steel members which are securely braced and riveted, is covered by a steel floor 0.95 cm. (3/8 in.) thick. At each end an operating compartment for the engineer is partitioned off from the apparatus room in the center. Current is collected by either of two slider-type air-raised gravity-lowered pantographs mounted on the roof.

When descending grades, the locomotive is held back by regeneration: five of the motors becoming generators while the sixth generates their exciting current. The locomotives are also equipped with vacuum brakes, but these are used only in emergencies and in bringing the train to a complete stop. On this railway, although practically all the passenger coaches are equipped with power brakes, the freight cars have only individual hand brakes which must be applied by the trainmen when a braking effort is required in excess of that which will slip the wheels of the locomotive. In actual freight service it is customary to have a man stationed on every fourth car to assist if necessary in braking the train. At present an average freight train consists of 28 to 36 freight cars of 15-ton capacity, which requires a large crew.

The normal train movement is "loaded" up-grade (from Ujo to Busdongo) and "empty" down-grade, although trains loaded to the rated capacity of the locomotive are also handled on the down grade. Favorable comments have been made by Spanish engineers on the easy riding qualities of these locomotives.

Their ratings, dimensions, and weights are given in Table I.

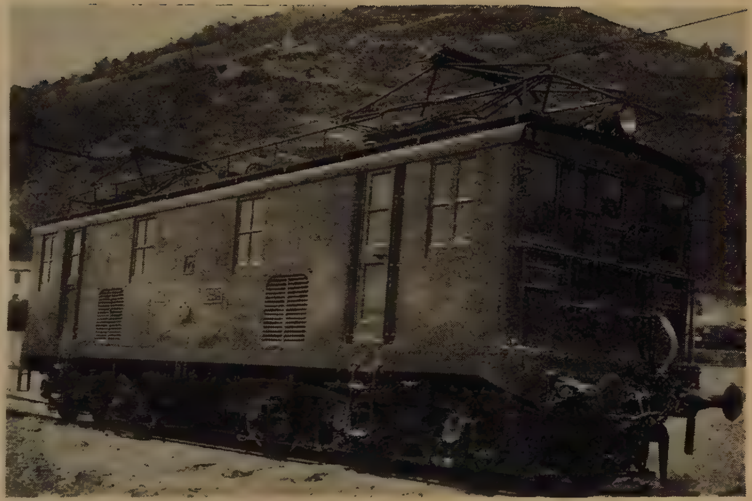

Fig. 3. One of the Six Direct-current, 3000-volt, 1550-h.p., 90-ton Locomotives

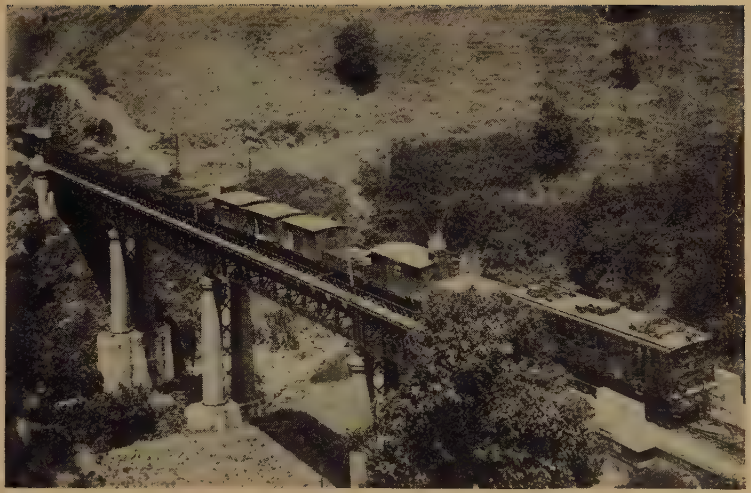

Fig. 4. Electric Locomotive Hauling a Typical Freight Train Over a Bridge Near Fierros

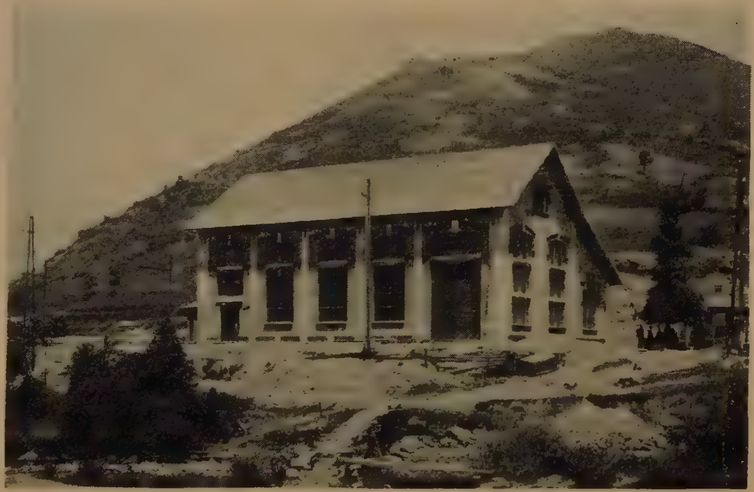

Fig. 5. Exterior of the Cobertoria Substation for Furnishing Power to the Northern End of the Line. The high-pitched roof prevents accumulation of snow

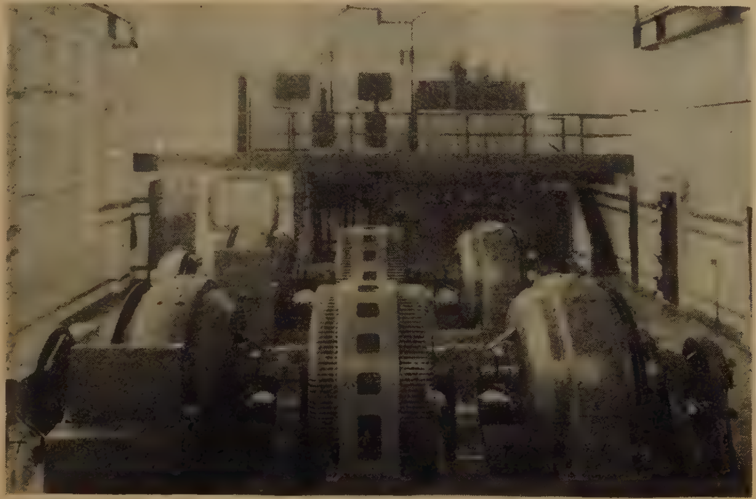

Fig. 6. Interior of the Cobertoria Substation, Showing Two 1500-kw., 3000-volt Motor-generator Sets, and Switching Equipment

Motors

The motors are of the commutating-pole box type with the air inlet at the top. Ready access to the armature, pole pieces, and field coils is provided through the pinion end. Large handholes allow easy inspection of the commutator and brush-holders. The bearings are waste-lubricated and an ample supply of oil is insured by auxiliary oil wells.

Louvres in the sides of the cab permit the entrance of air to the whole interior of the apparatus compartment. The blower drives air into the horizontal duct between the center channels of the locomotive platform. These ducts open through hollow center plates and flexible duct connections into the truck transoms, which connect with ventilating openings in the motors. The series method of ventilation is used; that is, air enters the top of the motor frame at the pinion end, is forced over the armature and field coils, returning through the commutator and armature core to the pinion end, whence it is expelled through holes in the framehead. These motors are designed for operation at 1000 volts per commutator and are insulated to operate three in series on 3000 volts.

The motor has a continuous rating of 258 h.p. at 1000 volts for a temperature rise of 120 deg. by resistance. The gears and pinions are of oil-tempered steel and have a reduction ratio of 72 to 18.

TABLE I

ELECTRICAL DATA

Nominal voltage system	3000
Tractive effort, cont.	12,000 kg. (26,500 lb.)
Tractive effort 1 hr., blown	12,300 kg. (27,100 lb.)
At 30% coefficient	24,400 kg. (53,700 lb.)
Total h.p., continuous	1550
One hour	1550
Speed, continuous	35.3 km.p.h. (21.9 m.p.h.)
One hour	34.8 km.p.h. (21.6 m.p.h.)
Number of motors	6
Gear ratio	4:1 or 72:18

MECHANICAL DATA

Track gauge	1675 cm. (5 ft. 6 in.)
Width	2.96 m. (9 ft. 8½ in.)
Length	14 m. (46 ft. 0 in.)
Max. rigid wheel base	3.5 m. (11 ft. 6 in.)
Diameter of drivers	100 cm. (39⅜ in.)
Total wheel base	10.67 m. (35 ft.)
Number of driving axles	6
H'ght over trolley down	4.1 m. (13 ft. 5 in.)

WEIGHTS

On drivers (total)	81,300 kg. (179,000 lb.)
Per driving axle	13,560 kg. (29,830 lb.)
Electrical equipment	38,600 kg. (85,000 lb.)
Mechanical equipment	42,700 kg. (94,000 lb.)

Control

The control is electro-pneumatically operated and is intended for non-automatic single-unit operation with the following connections: One group of six motors in series, or two groups of three motors in series.

Fourteen steps are provided for acceleration with six motors in series, ten steps with two parallel groups of three in series, and thirteen steps in regenerative braking. In starting, the six motors are connected in series with the line and an adjustable resistance. Sections of this resistance are short circuited as the controller is moved from point to point over the series travel of the main handle until all the resistance is cut out and the six motors are in series directly across the line. Then, as the accelerating handle is moved to the first series-parallel notch of the controller, a pneumatically operated transfer switch reconnects the motor circuits in the series-parallel arrangement with the resistances again in series. The short circuiting of the resistance is then repeated until the motors are in the full series-parallel position.

All the motor switching is performed by air-operated contactors. They are closed by compressed air and opened by a heavy spring. An arc chute and blower coil insure proper rupturing of the arc. An electro-pneumatically operated reverser is interlocked with the line contactors.

For speeds above the full-series and full-parallel connection, two reduced-field positions are provided. Both reduced-field positions can be obtained in either of the full-running positions. This is accomplished by moving a selective handle on the master controller. This controls contactors which connect an inductive shunt across the field. In emergencies three of the motors may be cut out and the locomotive operated with the remaining three.

Regeneration is accomplished by using one motor to excite its own field and those of the other five. The remaining five motors are connected in series and regenerate to the line in proportion to the field excitation. Only one combination of motors is used for regeneration but, by means of the 13 steps which are provided, a speed range from 20 km. (12.4 miles) per hour to the maximum operating speed of the locomotive is obtained.

Regenerative braking is accomplished by the same controller, contactors, and resistors as are used during motoring. This simplifies the control and makes economical use of the apparatus. A balancing resistance is

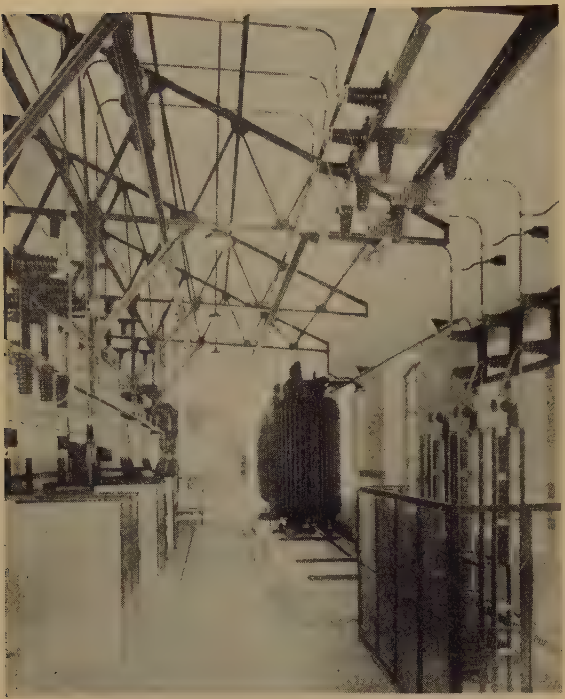

Fig. 7. Transformer Room at the Cobertoria Substation, Showing Transformers, Exide-film Lightning Arresters and High-tension Busses

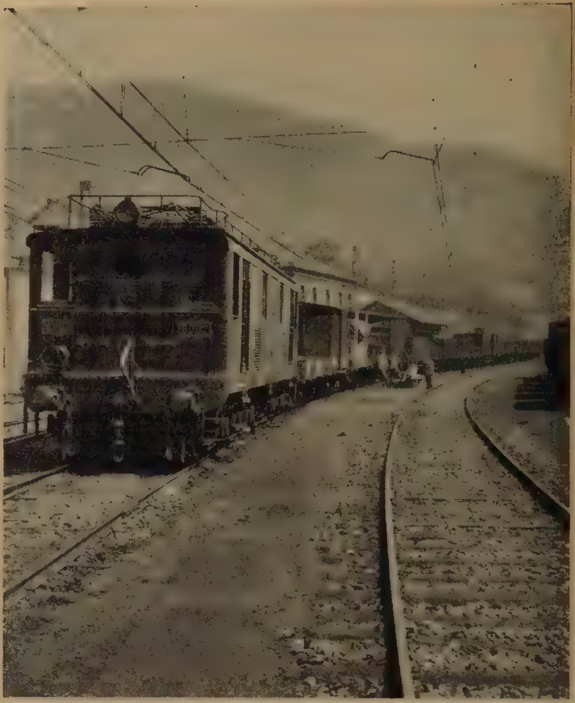

Fig. 8. Electric Locomotive and Train at Ujo, Showing Main-line and Yard Overhead

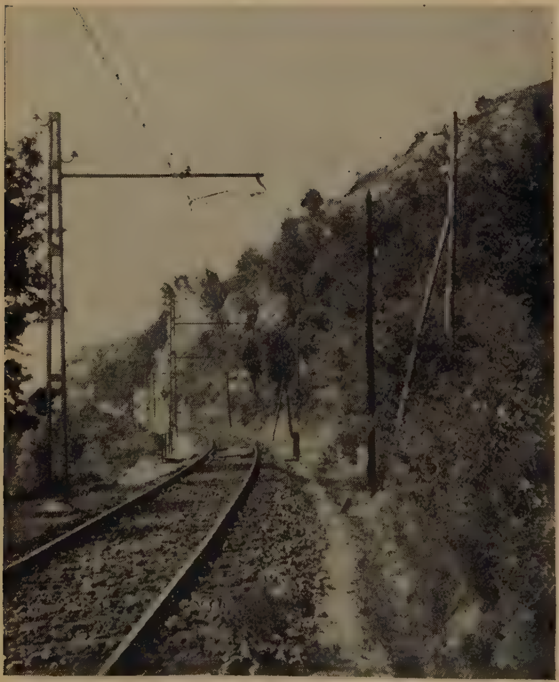

Fig. 9. Curve on Main Line, Showing Poles on Inside of Curve Supporting Feeders and Overhead

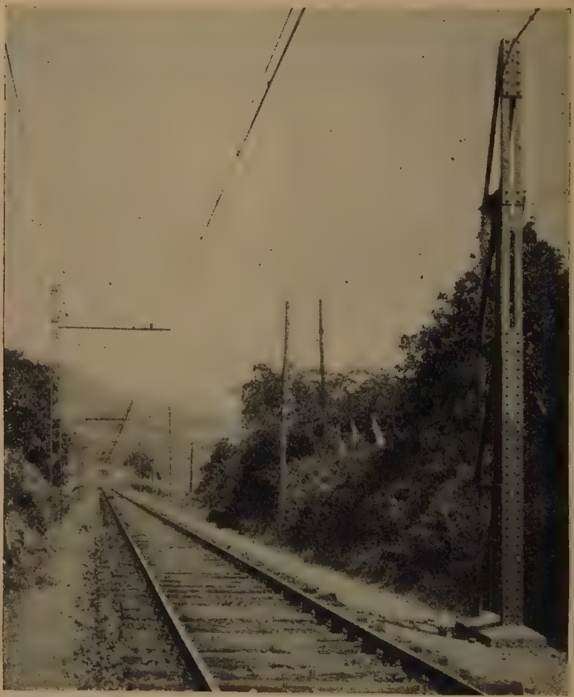

Fig. 10. Tangent Track Leaving the North End of the Cobertoria Classification Yards

used to protect the motors, to stabilize the excitation, and to compensate for line-voltage changes. When starting to regenerate, the main handle of the master controller is moved to the *off* position, and the selective handle then thrown to the braking connection. This same handle is used to select the motoring, reduced-field, and regenerative-braking connections. Upon setting the selective handle for the braking connection, a transfer switch is thrown by compressed air. This rearranges the circuits to give the connections necessary for regenerative braking. The main handle may then be notched up until the desired braking torque is obtained. The master controller is mechanically interlocked so that no false manipulation is possible.

Auxiliary Equipment

Power for the operation of the control circuits, lights, cab heaters, air compressor, exhausters, and for charging the storage battery is furnished by a 10-kw. 65-volt generator direct connected to a 25-h.p. 3000-volt motor. A blower mounted on the extended shaft of the motor-generator set furnishes air for the ventilation of the traction motors.

As a reserve there is provided a storage battery of a sufficient capacity to operate the control, an exhauster, and the lighting system for one hour. A reverse-current relay is placed in the circuit between the battery and the generator to prevent the discharge of the battery.

The compressor, which furnishes air for the controls, pantographs, whistles, and sanders, is operated from the 65-volt circuit, and is controlled by a governor which starts and stops it automatically, thereby maintaining the pressure between certain predetermined values.

Two exhausters, both of which operate from the 65-volt circuit, maintain the vacuum-brake system on the locomotive and the passenger coaches. Normally one exhauster operates at low speed, while the other is shut down.

A high-speed circuit breaker is connected ahead of all other apparatus in the main motor circuits. In case of a short circuit on any part of the apparatus, or of a heavy overload, the circuit breaker trips and opens the circuit. The high speed with which the breaker opens greatly reduces the liability of damage from either short circuit or heavy overload. In addition to protecting the locomotive, it also protects the generating units in the substation by quickly reducing any heavy power demands. The breaker has no mechanical latches or triggers. It is tripped electro-magnetically. The blow-out consists of a powerful magnetic field which combined with a narrow arc chute quickly breaks the arc caused by opening the circuit.

An overvoltage relay is connected across the regenerating motors in series with the high resistance, and is so arranged that when the motors generate a predetermined voltage this relay opens, tripping out the high-speed circuit breaker and dropping out the resistance contactors during regeneration so as to open the field of the motors. This furnishes protection against overvoltage in case of loss of trolley or substation load.

Substations

Power from the 30,000-volt lines will be converted to 3000 volts direct current in two substations, one of which is located at Cobertoria 9.5 km. (5.9 miles) from Ujo; the other at Pajares which is the same distance from Busdongo, the southern end of the electric zone.

Each of these stations contains two 3-unit 4-bearing 1500-kw. 3000-volt direct-current motor-generator sets with the necessary transformers and switch gear. Provision is made for the future installation of a third unit in each station. The outgoing positive feeders are amply protected by the addition of high-speed circuit breakers in each line.

Transformers

Two three-phase oil-cooled transformers rated 30,000/3500 volts, 1900 kv-a., 50 cycles are installed in each of the two substations. Four 2½ per cent taps are provided in the low-voltage winding to compensate for variation in the transmission line voltage and 50 per cent starting taps for starting the motor-generator sets.

Motor-Generator Sets

The direct-current generators are designed for 1500 volts per commutator and are permanently connected in series for 3000-volt operation. They are separately excited from a small 125-volt generator mounted on one end of the set. The series field of each main generator is designed to provide flat compounding from no load to 50 per cent overload. They are equipped with commutating poles and compensated windings to insure sparkless commutation under all load conditions.

Excitation for the synchronous motor is provided by a second 35- to 150-volt direct-current generator placed on the opposite end of the set. It has a series winding which carries the 3000-volt line current so that the motor-field excitation varies in proportion to the load on the set. This insures correct power-factor with varying loads, and also insures stable operation under heavy overloads. These sets handle 150 per cent load for two hours, 300 per cent load for five minutes. They also operate inverted to take care of regeneration.

Overhead and Line Construction

The overhead construction is of the modified flexible catenary type designed by the General Electric Company and installed under the supervision of the Sociedad Iberica de Construcciones Electricas. This overhead is known as the twin-catenary type and comprises two 4/0 copper wires flexibly suspended side by side from the same ½-in. dia. steel messenger by independent loop hangers. These supports are spaced 4.56 m. (15 ft.) apart and are alternately connected to each contact wire. Thus the distance between adjacent hangers is 2.28 m. (7.5 ft.) With this construction, due to the four contacts secured by the double-pan collector and the twin-trolley wire, current is collected under all conditions without visible sparking. Porcelain insulation is used throughout. Steel poles spaced at intervals of 45.6 m. (150 ft.) on tangent track, with reductions on curves, support the brackets carrying the messenger. Brackets on the poles carry the positive feeder and the negative return wire, while in tunnels these are carried on iron-bracket supports.

It is possible on account of the unusually circuitous route which the track follows to improve the distribution by running the feeder across the ends of several loops that are necessary to conform to the limiting grade. One of these cut-offs is 2 km. (1.24 miles) in length across about 7 km. (4.35 miles), while two others about ½ km. (0.30 miles) long join the ends of another loop of about the same length.

As it was deemed advisable to put in concealed bonds, it was necessary to install special fish plates throughout the electrified section. Each rail joint is bonded by 30.5-cm. (12-in.) 4/0 copper bonds, and at every 305 m. (1000 ft.) a 4/0 steel cross bond 193 cm. (76 in.) long is put in.

To protect the system, sectionalized construction is used. Due to the character of the country—mountains, curves, and tunnels—and to the fact that there must not be any interference to normal operation, all construction work was done at night. The copper wire used in the work was drawn and stranded at Cordoba, a noted manufacturing center in the south of Spain. Too much credit cannot be given the officials of the Spanish Northern Railway who took care of the design and construction of the substations and overhead line material. In this work they were ably assisted by the engineering staff of the Sociedad Iberica de Construcciones Electricas. Visiting railroad men and engineers who have inspected this electrification are particularly complimentary with regard to the fine appearance of the substations both inside and out and to the unusually substantial character and high-class workmanship in the installation of the overhead line material.

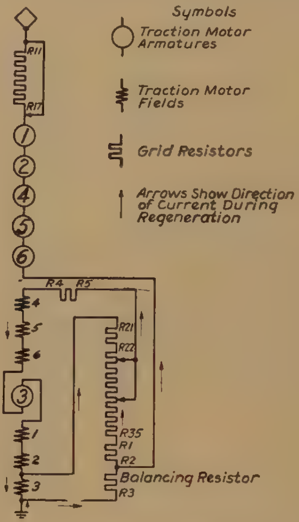

Fig. 11. Simplified Wiring Diagram, Showing Regenerative Braking Connections

The Davis Bridge Power Plant Development of the New England Power Company

By E. B. Collins
Assistant Electrical Engineer
New England Power Company

and

H. R. Wilson
Central Station Engineering Dept.
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This latest addition to the power plants on the New England Power Company's extensive system is unusual in many respects. The dam necessary to secure adequate water storage was made of earth by the modified hydraulic method and is the highest of its type in the world. Also in the design of the intake and the spillway, wide departures were made from conventional practice. By special arrangement of equipment and connections, the station is enabled to transmit at 66,000 and 110,000 volts simultaneously. From the plant a new 76-mile 110,000-volt line was built having towers that now carry a single circuit of that voltage, can accommodate a duplicate circuit in addition, or can in place of these two carry a single 220,000-volt circuit.
—Editor.

The New England Power Company's first development on the Deerfield River was at Shelburne Falls in the year 1913. This consists of three hydro-electric stations (Numbers 2, 3, and 4), there being installed at each station three 2000-kv-a. horizontal-type generators and two 3000-kv-a. transformers stepping up to 66,000 volts. The distance from Station No. 2 located on the lower level of the river to Station No. 3 is approximately three miles and Stations No. 3 and No. 4 are separated by approximately one mile. A short time later a 15,000-kv-a. development was completed near Hoosac Tunnel, Mass., and the next development was at Readsboro, Vt., in the year 1916 and consisted of a 3000-kv-a. unit. The water storage for these stations is located at Somerset, Vt., at the head of the Deerfield River and consists of a 1684-acre reservoir of 20 billion gallons capacity. The dam is made of earth and was constructed by a modified hydraulic-fill method. Sample borings of the dam were recently taken and showed a very homogeneous condition of material. The Searsburg Station, which was completed in 1920, is located 10 miles down river from the Somerset reservoir and 13 miles above Readsboro. This is a complete automatic station consisting of one 5000-kv-a. vertical generating unit. The water is received through a three-mile woodstave pipe line eight feet in diameter.

The latest development is at Whitingham, Vt., and is known as the Davis Bridge Development. This consists of two (ultimately three) 20,000-h.p. hydro-electric units.

In order to obtain water storage for this station, it was necessary to construct an earth dam 200 ft. in height. This is the highest dam in the world built by the modified hydraulic-fill method. The speed with which the dam was constructed is indicated by its having been started in June, 1922, and completed January 1, 1924, although the work was held up for over three months by severe weather. Further information concerning the dam is given in the following tabulation:

Height 200 ft.
Width of base 1300 ft.
Width of crest 25 ft.
Height of crest above sea-level 1525 ft.
Drainage area (below Somerset) 154 sq. miles.
Volume of dam 1,900,000 cu. yd.
Area covered by dam 18 acres.

Reservoir

The reservoir formed by the dam is 10 miles long and covers 3.5 square miles. The maximum depth is 185 ft. and the maximum operating draw-down is 90 ft. The capacity is 38 billion gallons.

Diversion Tunnel and Spillway

Before work could proceed on the dam it was necessary to build a 1500-ft. concrete diversion tunnel 22.5 ft. in diameter and of 20,000-cu. ft. per sec. capacity. After the completion of the dam the upstream end of this tunnel was plugged and the lower end of it used as a discharge passage from the spillway, which is called the "glory hole" on account of its resemblance to a morning-glory blossom. The top of the spillway is 14 ft. lower than the crest of the dam and it has a 185-ft. vertical drop. The diameter of the opening at the top is 160 ft. and at the throat is 22.5 ft. The length of the spillway is about 500 ft. and the capacity 30,000 cu. ft. per sec. In order to distribute the flow of the water into the spillway more evenly, and to prevent swirling, guide vanes are located radially on the top or nearly level part. These vanes also serve as piers for supporting the flashboards as well as a platform on which to handle them.

cross-section, being divided vertically by a concrete wall. The rounded part forms a dry shaft at the bottom of which are two valves which admit the water to the power tunnel.

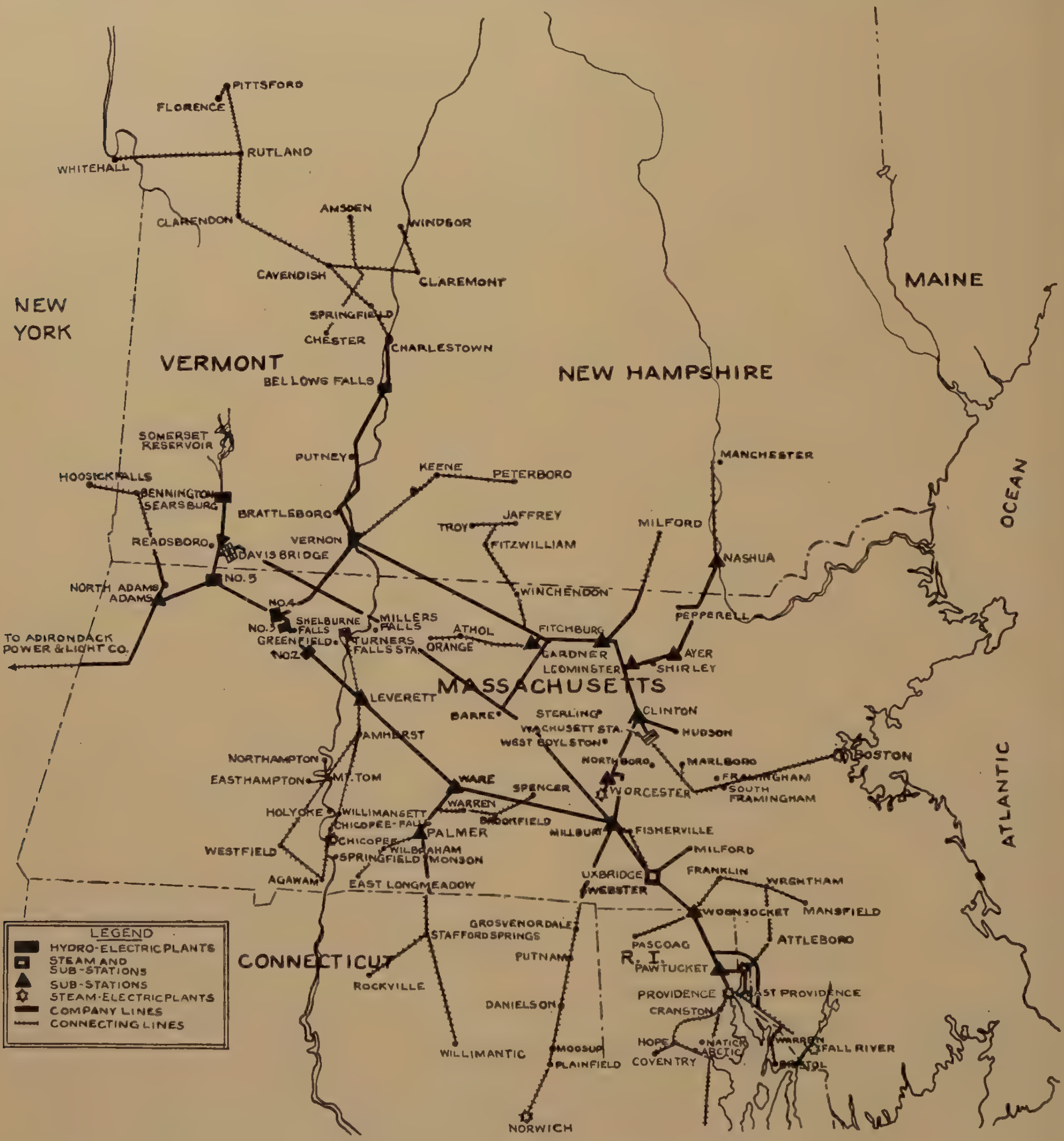


Fig. 1. Lines of the New England Power System and Connections

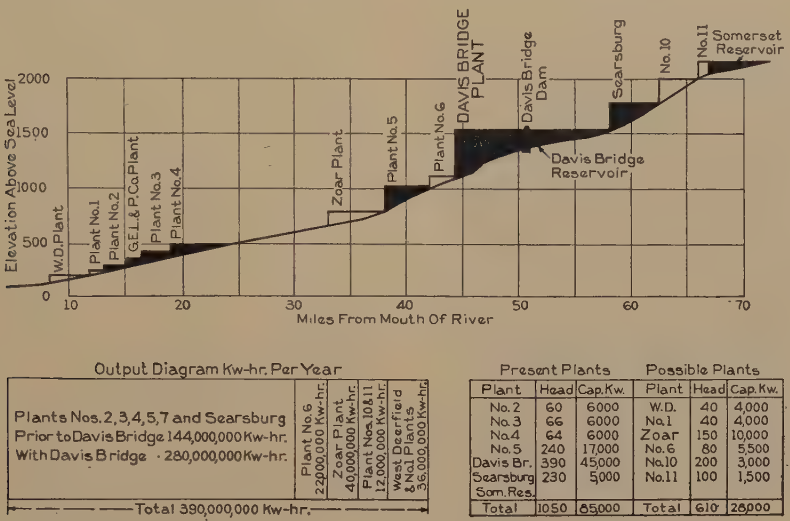
Intake Structure

The intake tower at the entrance to the pressure tunnel is of concrete and is located on the slope of the reservoir basin approximately 100 ft. above the original river bed. It is 125 ft. in height and is U-shaped in

The upstream side of the square part of the tower consists of racks extending the entire height of the tower and through which water is admitted to the valves. These racks are inclined from the vertical about 6.5 deg. and can be arranged for mechanical raking should the necessity arise. The valves are of the "Dow" disc-arm type which embodies the principle of exerting maximum pressure on the downstream half of the butterfly when it is in the closed position. There are two valves, 96 in. diameter, and it is possible to block the circulation of water through either one, remove it, and operate through the other valve at reduced capacity. The valves are operated by 220-volt three-phase alternating-current motors.

Pressure Tunnel

The power house is about 4.5 miles river distance from the dam but the intake tunnel is in a straight line 2.5 miles long. This tunnel is located in mica schist rock, is 14 ft. in diameter, and has a capacity of 1400 cu. ft. per sec. A six-inch concrete lining is used for otherwise the friction loss would have been so great as to require a cross-section nearly 100 per cent larger.



Present Plants			Possible Plants		
Plant	Head	Cap. Kw.	Plant	Head	Cap. Kw.
No. 2	60	6000	W.D.	40	4,000
No. 3	66	6000	No. 1	40	4,000
No. 4	64	6000	Zoar	150	10,000
No. 5	240	17,000	No. 6	80	5,500
Davis Br.	390	45,000	No. 10	200	3,000
Searsburg	230	5,000	No. 11	100	1,500
Som. Res.					
Total	1050	85,000	Total	610	28,000

Fig. 2. Profile of the Deerfield River and Data of the Power Plants

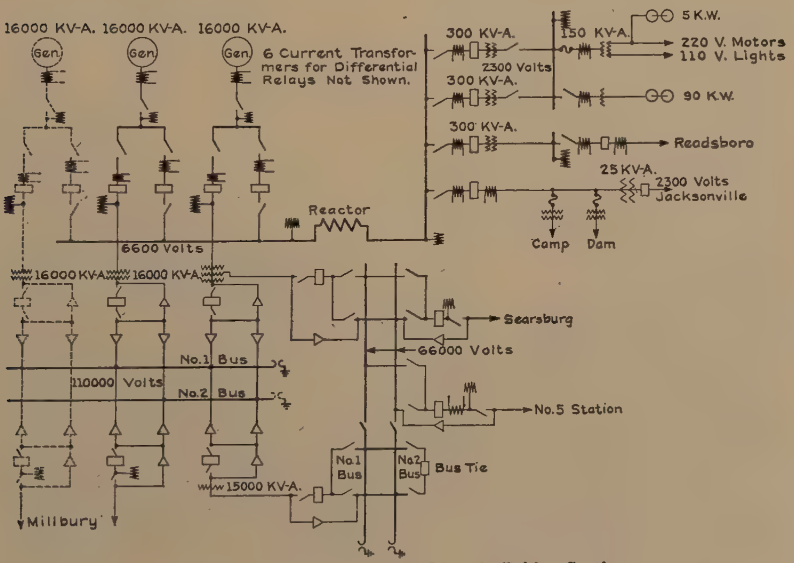


Fig. 3. One-line Diagram of Davis Bridge Station

Surge Tanks and Penstocks

The surge tank is of the Johnson differential type. Inside the main tank is a vertical 8-ft. diameter pipe rising to within a short distance of the top. Due to the 90-ft. draw on the reservoir, it was necessary to make the tank 184 ft. high. The diameter is 34 ft. The maximum plate thickness is 1.25 in. and the weight is 450 tons. The penstocks are each 542 ft. long, 9 ft. in diameter, have a 1-in. plate thickness, and weigh 350 tons.

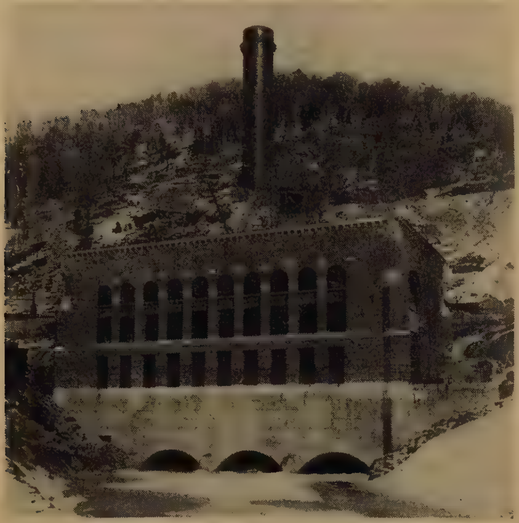


Fig. 4. Power House and Surge Tank

Generating Station

The power house was arranged for locating the generators and low-tension bus on the main floor, the low-tension oil circuit breakers on the first gallery, and the switchboard on the second gallery.

Turbines and Generators

The turbine equipment consists of three 20,000-h.p. vertical-shaft units, two of which are now installed. These will operate under a mean head of 350 ft., the maximum head being 390 and the minimum head 300. The wheels are of the single-runner type. The generators are rated 16,000-kv-a. 360 r.p.m., 6600 volts, and each is provided with a 90-kw. 250-volt direct-connected exciter. The generators are of the "semi-enclosed" type, i.e., the air enters at the bottom and top and is discharged outside of the station through suitable ducts. Doors are provided in the enclosing casing to permit the air to be discharged into the station for heating purposes if so desired. Either generator can be excited from a 90-kw. motor-generator set instead of the direct-connected exciter.

The generators may be put into service either manually or automatically. A control switch cuts into circuit the automatic equipment. When the generator speed has reached about 95 per cent of normal speed, a speed switch operates and closes the generator oil circuit breaker. The automatic closing of the field circuit immediately follows.

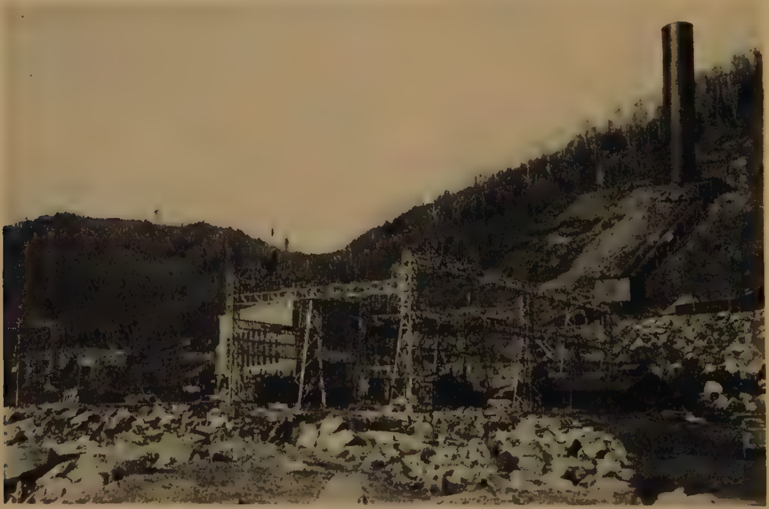


Fig. 5. 66,000-volt Switch Yard and Surge Tank

The generators are provided with pneumatically operated brakes supported by the lower bracket arms. These brakes may also serve as jacks in which case they are operated by a manually operated oil pump. Each generator is provided with a unit oiling system. A pump is geared to the generator shaft; and the oil circulating path is through the thrust bearing, the upper guide bearing, the lower guide bearing, and the filter.

Low-Tension Switching Equipment

The switchboard is of the vertical panel type, and consists of main and auxiliary boards, back to back. The control and instrument cables are carried through a large floor duct, located between the two boards, to terminals at the base of the panels and thence through 4-in. vertical fiber ducts to the instruments. The floor duct has removable iron covers, and the 4-in. fiber ducts are vertically split with circular clamps holding the halves together. This construction, combined with the use of different colored leads, provides a comparatively clear space back of the boards and yet affords a ready access to any cable. A signal system with "Phase," "Release," and "Stop" signals connects the operating gallery and the individual machines.

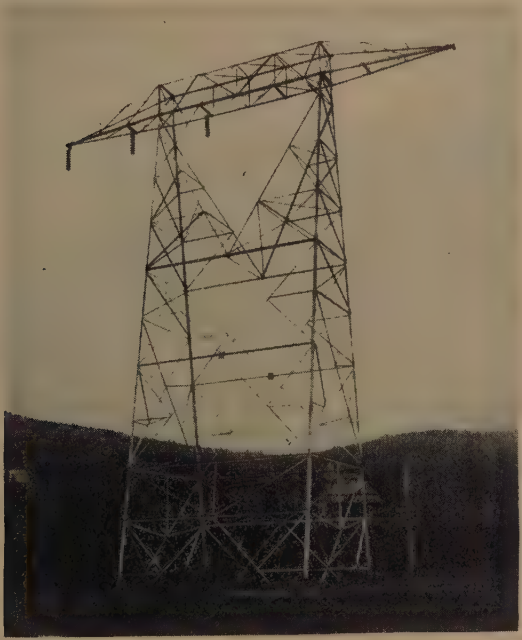


Fig. 6. Transmission Tower on the 76-mile Line. Can be used for two 110,000-volt or one 220,000-volt circuits

The low-tension busses are carried in concrete troughs located on the main floor. The station service and local feeder busses are carried in fiber tubes imbedded in the concrete walls. The feeder and breaker connections are made through small port-holes cored out in the concrete walls. The generator and transformer cables consist of three 3-conductor lead-covered cables per unit, each conductor being of 1,000,000 cir. mil cross section.

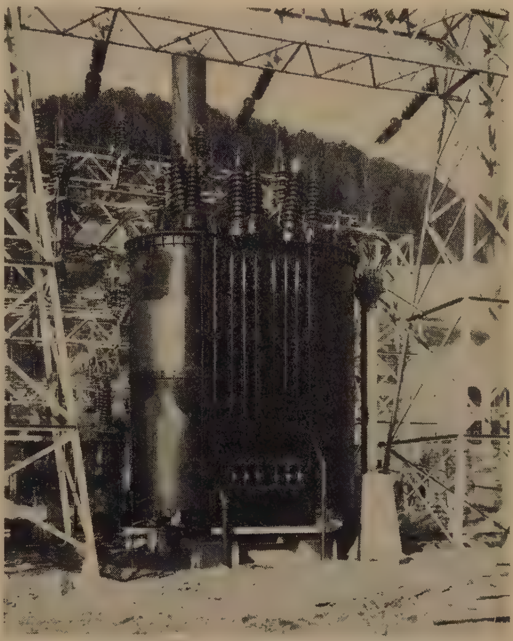


Fig. 7. 16,000-kv-a. Transformer for Stepping Up from 6600 Volts to 66,000 and 110,000 Volts Simultaneously

The local distribution and station service is obtained from a 300-kv-a. transformer bank, stepping down from the 6600-volt bus to 2300 volts. Station lighting and auxiliaries are operated at 115/230 volts from a transformer stepping down from the 2300-volt bus. A 144-kv-a. reactor limits the short-circuit current through these banks and thus permits the selection of relatively low interrupting capacity breakers for these circuits.

High-Voltage Equipment

The outdoor switch yards, both 110,000-volt and 66,000-volt, are of the box girder type, all steel being galvanized. In the 110,000-volt yard one main structure supports the double main busses of 400,000-cir. mil copper and the cross busses of 4/0 copper, also the air-break selector switches which are provided for the high sides of the three transformers and the 110,000-volt line. Oxide-film lightning arresters having a rating of 110,000 volts are connected to the main busses through inverted type disconnecting switches, also carried on the structure. The transformer and line oil switches are mounted under steel structures located adjacent to the main bus structure, and are provided with shunt and isolating switches, so that any oil switch may be taken out of service for inspection or repairs at any time without disturbing the flow of energy in the circuit. The cooling water for the transformers is supplied from a tap made to the penstocks with an auxiliary supply furnished by a motor-driven pump taking water from the tailrace. The supply and discharge water lines are carried in the trench adjacent to the 6600-volt cables from the generators to the transformers, so that advantage can be taken of these water lines for dissipating heat liberated by the cables.

There is located underground in the central part of the 110,000-volt yard a 10,000-gal. oil tank having a piping system provided with outlets near each transformer and oil switch. A pipe from the tank connects with the air system in the station, so that oil in the tank can be forced back through a filter press into the transformer or switch tanks. The oil switches are all operated from the switchboard in the station by means of 250-volt direct-current control. One main 250-volt lead-covered operating bus runs from the battery panel within the station to junction boxes located in the yard adjacent to each oil switch. The cables which control the several switches also terminate in these junction boxes, as do also the cables carrying current from the bushing-type current transformers of the oil switches and transformers. The junction boxes are provided with small knife switches through one of which each secondary wire is carried to facilitate testing.

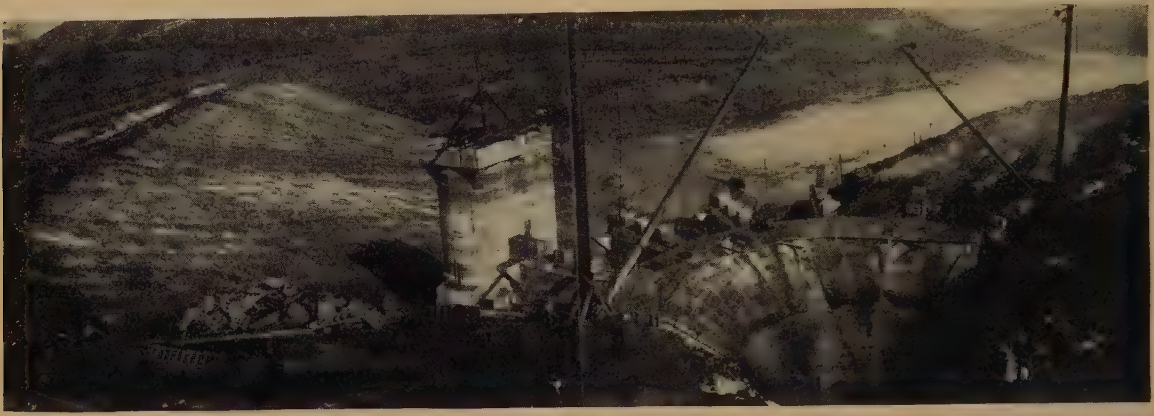


Fig. 8. Reservoir Under Construction, Showing the Intake Structure and the "Glory-hole" Spillway in the Central Foreground

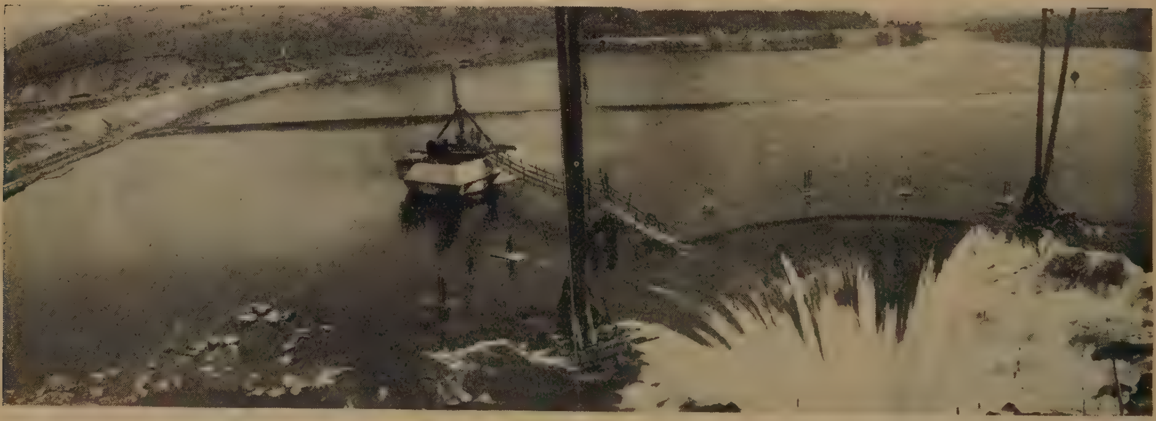


Fig. 9. Reservoir Filled. The converging discharge into the unique type of spillway is clearly shown

Potential transformers are connected to the 66,000-volt and 110,000-volt lines for synchronizing.

Transformers

The transformers are of the three-phase, water-cooled, core-type construction, having disc high-voltage windings and helical low-voltage windings. In order to transmit at both 66,000 and 110,000 volts simultaneously and also to "tie in" these two transmission voltages, three different transformer designs are used; these being as follows:

> An auto-transformer of 15,000-kv-a. output ties in the 66,000 and the 110,000-volt busses. Two 16,000-kv-a. transformers step up the 6600-volt generator potential to 110,000 volts, one of these being provided with taps for connecting to the 66,000-volt bus so that it can also be used as a spare to the auto-transformer, i.e., it will transmit in either direction between the high-tension busses and simultaneously from the 6600-volt bus to either high-tension bus.

The step-up transformer neutrals and the auto-transformer neutral are grounded, and as the delta-connected windings of the step-up units form a path for the circulation of the triple-harmonic current, an auxiliary delta-connected winding was not furnished in the auto-transformer.

Provision is made so that the transformers can be moved on a truck into the station which affords crane facilities for "untanking."

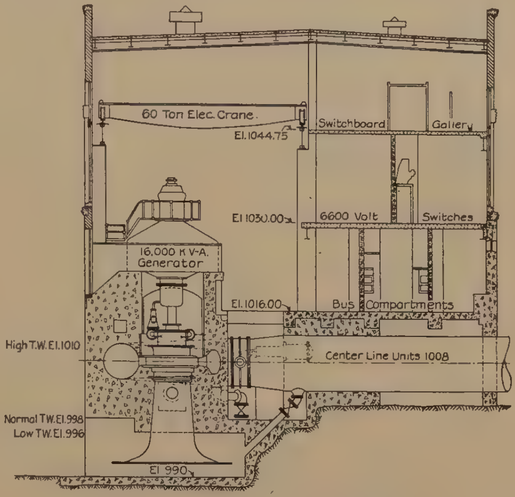


Fig. 10. Cross-section of Power House

Ratio adjusters are installed in all the transformers so that the taps can be changed from the outside of the transformer tank.

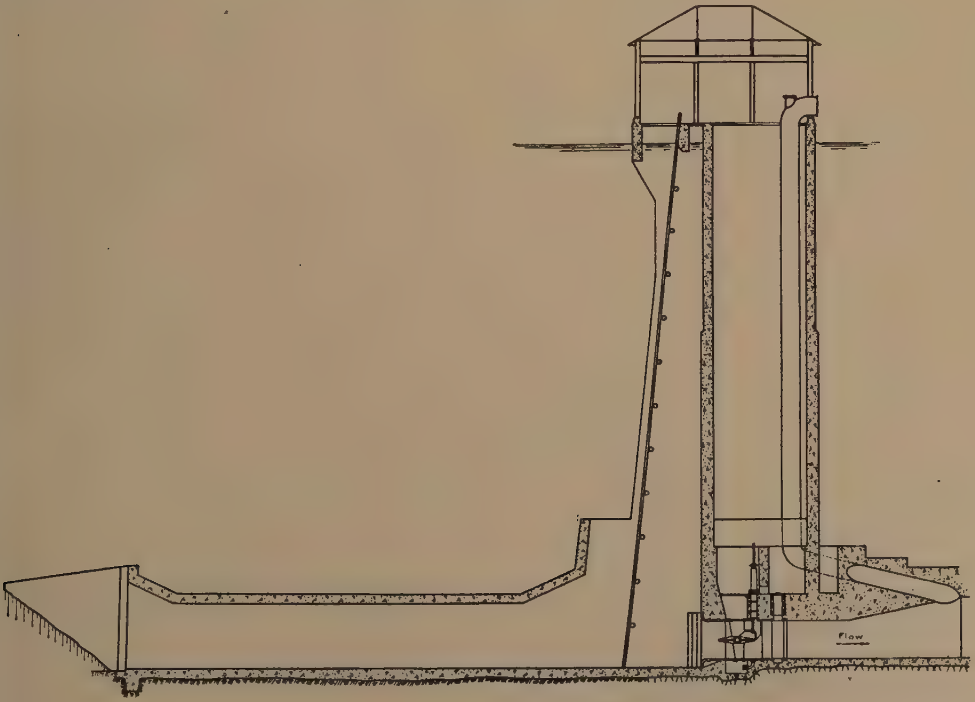


Fig. 11. Intake Tower and Tunnel

Transmission

The system transmission potential previous to the Davis Bridge Development was 66,000 volts. The towers and the line from Station No. 5 to Milbury were designed so that at a later date the line could be changed to 110,000 volts. It was found, however, that the cost of recoppering and reinsulating this line for this voltage, combined with the necessary sub-station changes, was enough to throw the decision in favor of a new line, especially when the operating advantages of an additional line were taken into account. This arrangement meant that the Davis Bridge Station must transmit at both 66,000 and 110,000 volts.

The design of the 76-mile 110,000-volt line received very careful attention because of the uneven topography of the ground over which the line was to run and the severe weather conditions to which it will be subjected. The course of transmission is practically a straight line from Davis Bridge to Milbury. One three-phase circuit consisting of 4/0.7 strand copper with three transpositions, and one ground wire ($\frac{7}{16}$-in. stranded crucible steel) are at present installed, and another three-phase circuit and ground wire are to be installed at a later date. There are eight suspension and nine strain units to a string of insulators. A single three-phase 220,000-volt circuit may be substituted on the same towers if it should be desired to do so in the future. The right-of-way is 250 ft. There are 565 towers, the average span being about 800 ft. When the second 110-kv. line is installed, it is proposed to have two sectionalizing points. The tower footings are 8 ft. deep and the height of the cross-arm above the ground varies from 50 to 70 ft. Stub lengtheners of standard lengths with holes spaced to match corresponding hole spacings in the towers greatly facilitated the erection on the uneven terrain. Tractors were used for hauling the steel and stringing the copper. The employment of a supervisory engineering foreman in the erection of these towers gave extremely satisfactory results. The towers are designed for the following conditions:

- Suspension towers for 900-ft. span and 4/0 copper loaded with ½-in. ice, plus 8-lb. wind, and 2 broken cables at 3500 lb.
- Strain towers for above loads, plus 8 broken cables at 4000 lb., plus 15 deg. angle in line.
- Towers also investigated for a radial ice load of 1¼ in., plus 4 lb. wind.
- Tower spacing, 7.6 per mile.

	Suspension Towers	Strain Towers
Weight above ground, lb.	9600	11300
Earth anchors, lb.	2500	3300

The telephone wires are not carried on these towers but on a separate pole line.

Operation

In normal operation each generator is connected to its transformer and but one generator to the low-tension bus from which the auxiliaries receive their power. This follows out the general "unit arrangement" in which each generator is furnished with its individual oiling system, direct-connected exciter, voltage regulator, and transformer. The transformers step up to the 110,000-volt bus, and the autotransformer connects the 66,000- and 110,000-volt busses with normal power flow from the 66,000- to the 110,000-volt circuits.

Internal Combustion Electric Locomotives

By Hermann Lemp

Recently Engineer, Internal Combustion Engine Dept., Erie Works,
General Electric Company
Now Consulting Engineer, Erie Steam Shovel Co., Erie, Pa.

The internal combustion engine is virtually a complete power plant in itself, and a highly economical one even in the smaller sizes. These qualifications ideally fit it for transportation service where the prime mover ravels with the carrier. However in some types of this service, for example rail transportation, it is necessary hat a variable-ratio transmission be employed to adapt the inherent speed-torque characteristic of the engine o the drive. The interposition of an electric generator and motor between the engine and wheels furnishes an efficient and reliable transmission having an infinite number of speed ratios. Before leaving the General Elecric Company, Mr. Lemp delivered before the Erie Section of the A.I.E.E. a very interesting paper on these nternal combustion electric locomotives of which the following article is an abstract.—Editor.

The internal combustion engine is the most efficient prime mover in existence today and the ease with which power may be obtained, particularly from liquid fuel, has led to its wide application on land, water, and in the air. In fact, the conquest of the air is due solely to the internal combustion engine; and n this connection it is interesting to note that f all the Liberty aviation engines, built during the war, were flying in the air at the same moment, there would be as much horsepower developed as Niagara Falls is furnishing.

General Characteristics of Drive

A normally designed internal combustion engine when running with open throttle has within practical limits the inherent characterstic of furnishing substantially a constant torque and a horsepower proportional to the speed.

When running by governor at nearly constant speed, the horse power will be proportional to the torque taken from the engine by the demand of service. However, n either case, if the torque is exceeded the engine will stall. It is therefore necessary to interpose between the prime mover and the oad a variable speed torque transmission which may be mechanical (as in most automobiles), hydraulic, pneumatic, or electric.

Experience with rail motor cars and ocomotives has thus far shown that mechanical transmission is practical up to about 15 tons of vehicle weight, that hydraulic transmission will work up to 15 tons and may go higher, and electric transmission is satisfactory above 15 tons, and more so the higher the weight. Pneumatic transmission has been used only experimentally and has not s yet been applied successfully in a practical manner.

Just as the internal combustion engine is he most efficient producer of power, so is the electric motor the most efficient and obedient servant or translator of power.

Advantages

Turning therefore to electric transmission between prime mover and load as the principal subject of this article, its chief advantages are summarized as follows:

(1) Lower cost of maintenance
(2) Greater reliability
(3) Superior control.

Maintenance

The cost of maintenance is less because the apparatus is less subject to shocks and therefore requires fewer renewals. All parts of the engines are easily accessible, due to the possibility of mounting the apparatus in any position desired. Its location permits making reliable water, gasoline, and oil connections, and the placing of the radiator on the roof where it is protected from flying stones and general misuse.

Electric equipment has demonstrated its low cost of maintenance in railway service, and the electric motor in particular is generally acknowledged to be the most sturdy piece of apparatus in railway service.

Reliability

Electric equipment possesses greater reliability for the following reasons:

Speed changes are made without shock to the apparatus.

It is elastic.

The engine is mounted on felt on the spring supported frame and is not subjected to hammer blows when passing over crossing frogs and switches.

It is free from dust and flying material in the bearings and the piping.

Minor defects are easily detected and adjusted before they become serious, due to the accessibility of the engine.

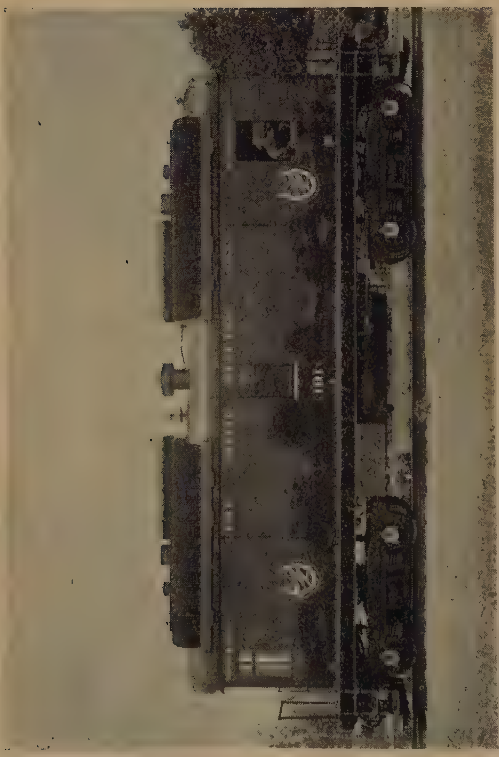


Fig. 1. Gas-electric Locomotive Having Two Prime-mover Units Electrically in Multiple on the Dan Patch Electric Lines

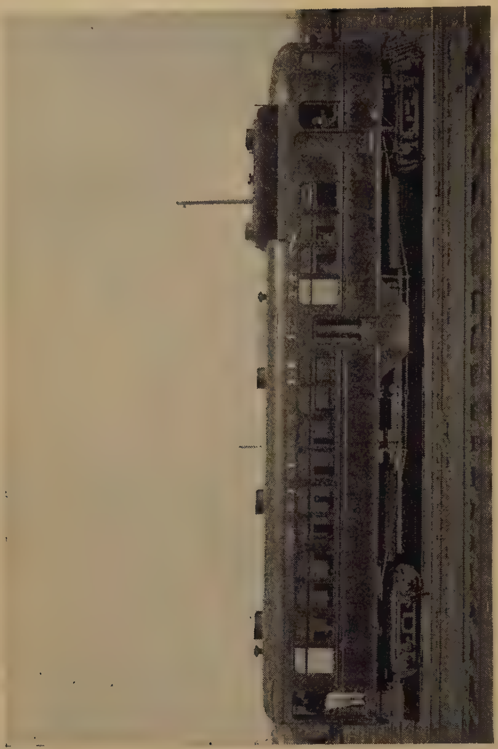


Fig. 2. Motor Car of Gas-electric Type on the Southern Railway

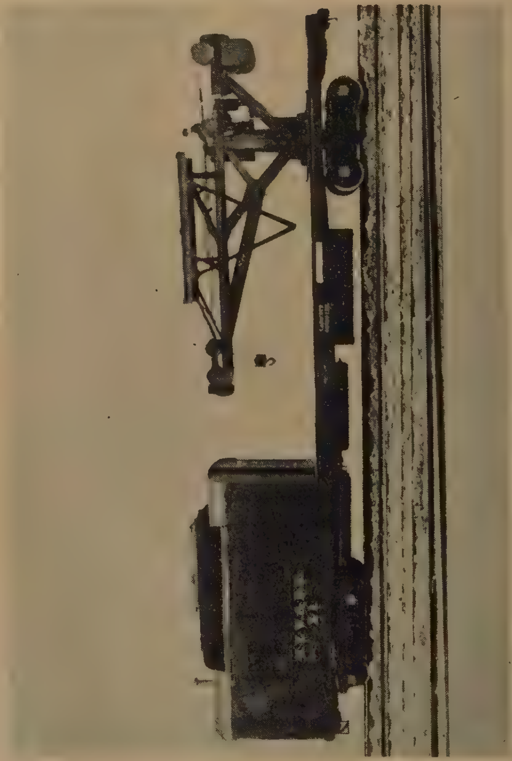


Fig. 3. Gas-electric Construction Car on New York, Westchester & Boston Railway

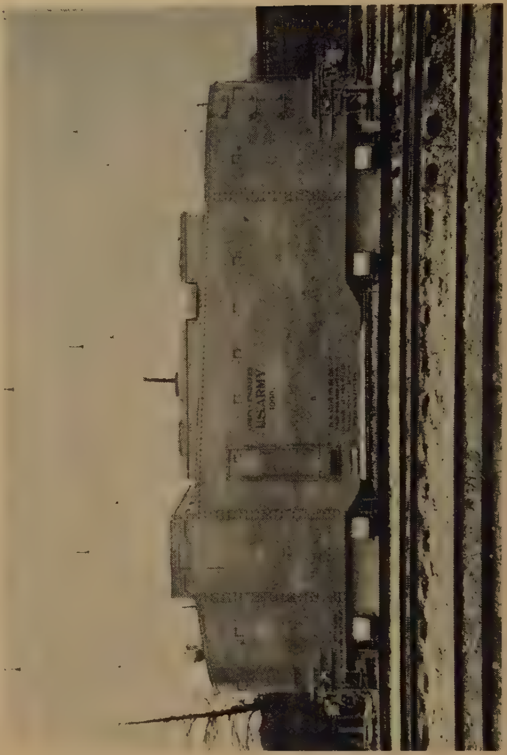


Fig. 4. Light Armored Oil-electric Motor Car. Part of Engineering Corps' Equipment, U.S. Army

Control

The control is superior to clutches and change gears for the following reasons:

Electric drive is equivalent to an infinite number of speed relations between the engine and car wheels, without any changes of clutches and gears. The full engine output is available at all car speeds.

It permits driving through two or more axles, which is a considerable advantage on grades or slippery rails.

The rigid wheel base of the driving truck may be short, permitting the use of shorter curves or "Y's" and turnouts.

Starting and acceleration is accomplished with absolute smoothness.

Conditions such as hauling additional trailers or negotiating heavy grades can be met, which might be impossible if the maximum tractive effort of the locomotive or car were rigidly fixed by the gear ratio.

In case of failure of the brakes, the motors may be used to stop the car.

The engine can be loaded full at all speeds, thus tending toward fuel economy.

High car speed may be obtained with low engine speed under certain conditions, and low car speed with high engine speed can also be obtained when desired.

The electric drive may be briefly described as follows:

A prime mover and direct-connected generator supply current through a controller to the motors on the truck without any intervening resistances.

Electric transmission is so easily controlled either by hand or automatically that one may make the broad statement that *all electric controls are good*, but some of them are better.

The methods of control may be properly divided into two fundamental types:

(1) That in which the prime mover is operated at *nearly constant* speed under the control of a speed governor, and the electrical energy delivered to the motors is modified by field excitation of the generator.

(2) That in which the speed of the prime mover is varied within wide limits, and the excitation of the generator field is controlled separately.

Constant Engine Speed Operation

When constant engine speed is employed, as is usual in stationary power plants and marine propulsion, the efficiency of the generator is at its maximum at full output, full speed, and falls off toward light loads. Where the service demands constant load, such as for main line locomotives traveling a long distance under steady pull, this method may prove the most economical and cause the least complication, particularly if the internal combustion motor is of the Diesel air injection type using heavy oil as fuel.

For this service a modified Ward-Leonard method of control is ordinarily employed. The original Ward-Leonard control comprises a generator whose field is separately excited through a variable resistance and whose polarity is also changed by reversing the direction of the exciting current, in connection with a motor directly connected to the generator without any intervening resistances, but having a fully saturated field excited from the same exciting source as the generator. The motor is therefore accelerated, decelerated, stopped, reversed, and accelerated in the opposite direction by changing the polarity and volume of the exciting current in the main generator field.

For traction work, this Ward-Leonard control has been modified: First by exciting the generator always in the same direction, only varying its strength; and second by using a series motor and reversing its rotation by reversing the flow of current through its armature. The generator speed being constant, the torque varies with the load and the excitation of the generator field.

Variable Speed Engine Operation

The control of engine speed by means of either a throttled carburetor, or a variable capacity fuel pump, is the method commonly used in automobiles or motor boats, and was adopted by the General Electric Company at the start in connection with gas-electric automobiles, buses, rail motor cars, and locomotives.

This fundamental method of control may be subdivided into a number of modifications as follows:

The engine is operated at variable speed by:

(a) A speed governor whose range of action may be varied
(b) A speed governor whose relative speed to the engine speed may be varied
(c) By hand adjusting the throttle or fuel supply to the engine
(d) By providing the engine with overspeed or underspeed governor or both, and adjusting the speed between the two governor settings by hand.

With any adjustable governor speed the excitation of the generator field can be hand controlled to keep the engine loaded to its full torque (which is equivalent to an open throttle). Carrying the excitation farther would stall the engine. This method gives probably the best average fuel efficiency and the longest life of the engine, but is open to the criticism that a *skilled operator* is required.

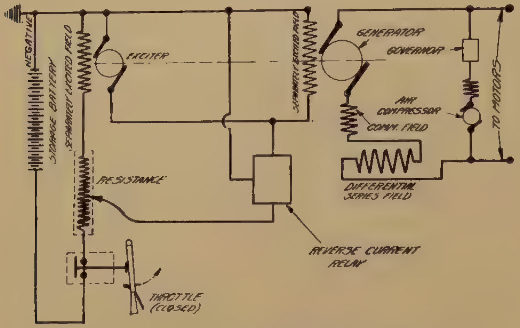


Fig. 5. Wiring Diagram of Electric Control for Gas- and Oil-electric Locomotives, Showing Automatic Feature

By locating on either side of the normal position of the swinging arm of a speed governor, valves admitting air alternately to either end of a cylinder, a piston traveling therein may be made to progressively increase the torque of an engine by opening its throttle. With the throttle remaining wide open a further movement of this piston will gradually unload the generator by introducing resistance in the generator field, thereby automatically producing a load suitable for the engine at any governor speed setting determined by the operator. The same result may be obtained by moving the piston electrically by means of contacts and electric motor control.

A third method is the one used on the switching locomotive at the Erie Works of the General Electric Company. In this locomotive, Fig. 8, the prime mover drives, through flexible couplings on the same shaft, a generator and exciter. The field of the exciter is energized from a storage battery and the exciter armature in turn excites the field of the main generator. The current from the main generator passes through a commutating field and a differential series field and thence through the motors constituting the load. This method of control is diagrammed in Fig. 5. Assuming the engine to run at any particular speed, the field excitation of the generator will be modified by the current flowing through the load to suit its own needs, drawing substantially constant energy within wide limits.

The operator in moving the throttle lever from the idling position toward the full-speed position first excites the exciter field from the storage battery, then increases the speed of the engine and thereby determines at any particular point the amount of horse power he wishes to use. *The form, however, in which that energy is taken by the motor is determined by the load itself.*

The resulting volt-ampere curve furnished by the generator at any particular speed is shown in Fig. 6.

This method of control is eminently suited for a switching locomotive where variable load is the rule of service. In its practical application the control has been made to approach that of a steam locomotive as nearly as possible, the throttle representing that of a steam engine, the controller handle the reversing bar, and the air brake the same in both. Hence it has been invariably our experience that any steam engineer would take to the operation of this locomotive with the greatest ease. The layout and assembly drawing of an oil-electric locomotive is given in Fig. 7.

Historical Review

With the understanding of the fundamentals it may be interesting to look backward on the previous history.

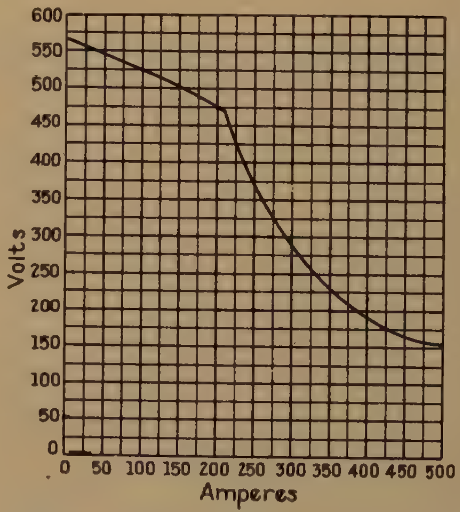


Fig. 6. Volt-ampere Characteristic Curve of Gas-electric Locomotive Illustrated in Fig. 8

The General Electric Company was an early advocate of electric drive as applied to internal combustion engines, and under the leadership of W. B. Potter, H. G. Chatain, W. E. VerPlanck, the writer, and their associates had started the building of gas-electric motor cars as early as 1909. Eighty-eight equipments have been put into service, most of which are still operating; and it is due to the service record established by these equipments that the railroads at this time, on their own accord, are requesting new equipments to be built.

Engine for Gas-electric Car

The gasoline engine used for the gas-electric motor cars built by the General Electric Company is an 8-cylinder 4-stroke engine as shown in Fig. 11, having an 8-in. bore and 10-in. stroke and running at 550 r.p.m. The cylinders are arranged "V" type at an angle of 45 deg. The engine is rated at 200 b.h.p. maximum (175 normal).

As the cars operate in all parts of the United States, the engine has been so designed that it will work satisfactorily with water at boiling temperature. In northern locations, during winter service, canvas hoods are used to cover the radiator during extremely cold weather. The inside of the car is also provided with a coal heater which not only furnishes heat for the car itself but which can also be used to maintain the temperature in the engine jackets overnight. Provision is also made for draining the water from the radiator into a tank in the engine room to prevent freezing. This water is returned to the radiator by air pressure as soon as the engine is started in the morning.

During the war the factories were turned over to the production of war products and at the conclusion of the armistice the General Electric Company decided to concentrate upon the building of electrical apparatus and to arrange for the manufacture of gas and oil engines by other builders.

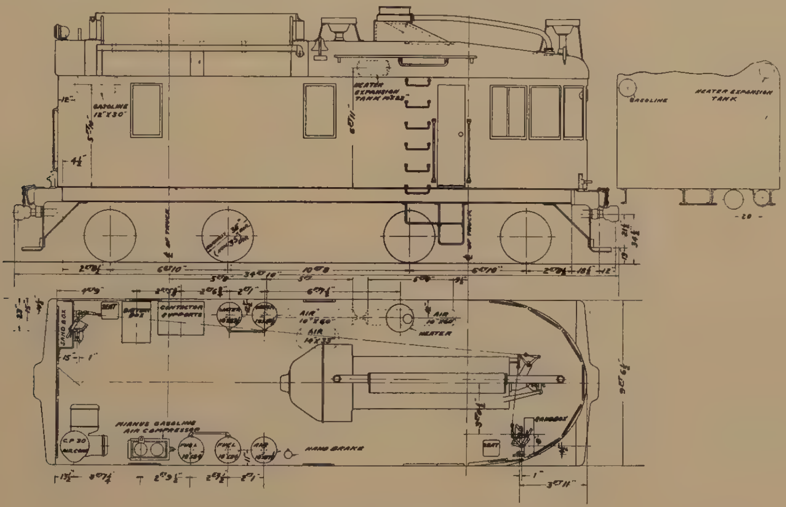


Fig. 7. Assembly Drawing of Oil-electric Locomotive Fitted with the Ingersoll-Rand Oil Engine Shown in Fig. 12

The Sterling-Dolphin Engine

One of the engines used is known as the Sterling-Dolphin engine, which is built with 6 cylinders and has a rating of 180 h.p. One of these engines is installed in a switching locomotive, shown in Fig. 8, at the Erie Works. This locomotive has been used extensively on the East Erie Commercial Railroad hauling a train as heavy as 350 tons up a 1½ per cent grade. It has also been used for handling an electric snow plow over tracks not equipped with a trolley, furnishing power through a cable to operate the revolving brushes.

The Sterling engine has also been used in a 40-ton gas-electric locomotive, Fig. 9, recently built for the Pittsfield Works. This locomotive is equipped with two master controllers, one in each end of the cab, for double-end operation.

The "GM-50" Engine

In connection with the study of possibilities of an oil engine for use on a switching locomotive, the so-called GM-50 engine was designed at the Erie Works, and some of these were installed on oil-electric locomotives. This engine is of the "V" type with 4 win cylinders and is capable of an output of 100 kw. at 550 r.p.m.

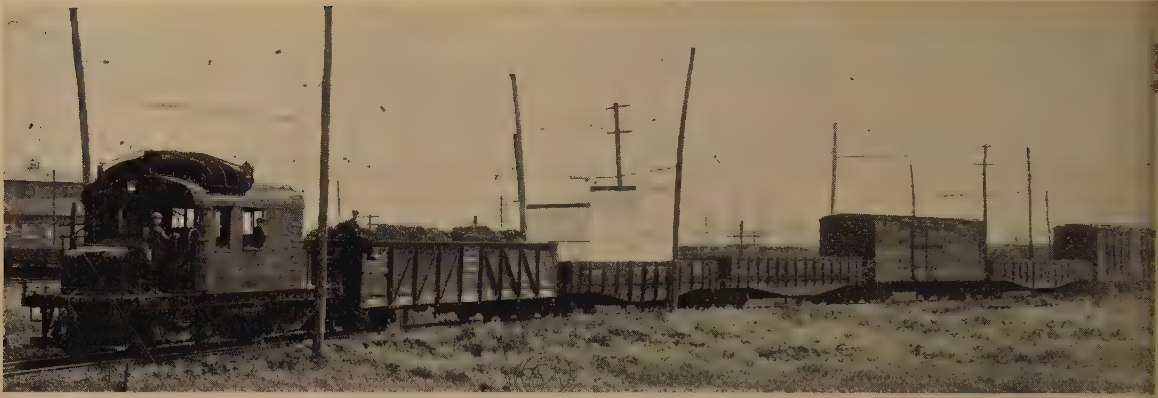


Fig. 8. Gas-electric Locomotive Equipped with Sterling-Dolphin Engine Hauling Nine-car Train Weighing 353 Tons

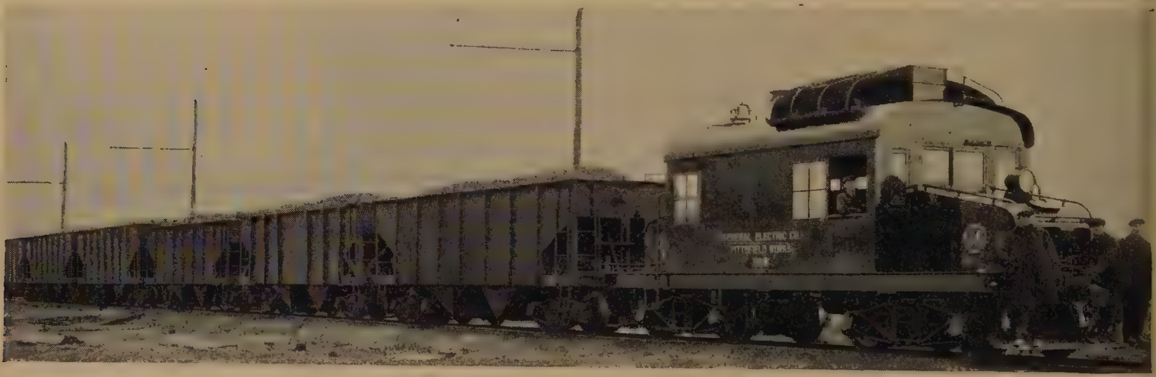


Fig. 9. Forty-ton Gas-electric Locomotive Having Two Master Controllers, One in Each End of Cab, for Double-end Operation

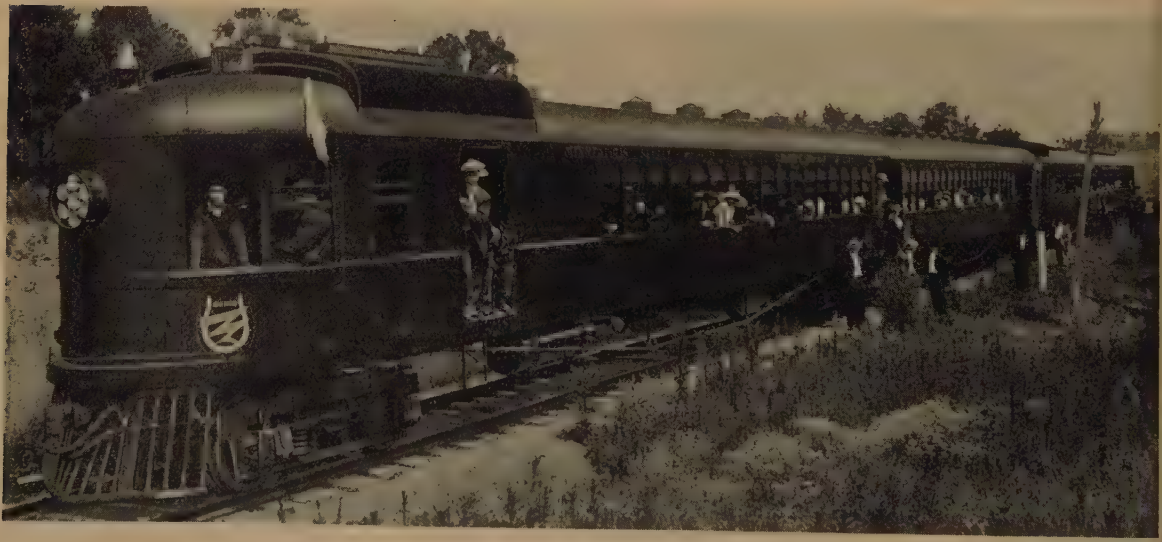


Fig. 10. Four-car Train, Consisting of Two Gas-electric Motor Cars and Two Coaches on the Minneapolis, St. Paul, Rochester & Dubuque Electric Traction Company's Lines

In selecting a type of oil engine suitable for locomotive service, specifications were prepared and placed with several reputable engine builders. It was particularly specified that the engine should operate without high-pressure air and that the fuel should be injected in some approved manner without air, or by the method usually termed "solid fuel injection." Among those who undertook to build such an engine was the Ingersoll-Rand Company, a brief description of whose engine is given below. This engine is rated 300 h.p. and was first installed in a 60-ton electric locomotive built at the Erie Works.

The Ingersoll-Rand Engine

The engine, illustrated in Fig. 12, is of the vertical 6-cylinder, 4-stroke cycle solid injection type using the Price type of combustion chamber. A single eccentric driven injection pump running at three times engine speed furnishes oil to all six cylinders. A distributor driven from the side shaft directs the oil to the proper cylinder.

The specifications of the engine are:

Number of cylinders	6
Bore	10 in.
Stroke	12 in.
Maximum speed	600 r.p.m.
Idling speed	200 r.p.m.
Rated b.h.p.	300
Weight of engine alone	17,000 lb.
Weight of engine and generator	26,750 lb.
Over all length of engine and generator	15 ft. 6 in.
Over all height	7 ft. 2 in.
Minimum air pressure required to start engine	125 lb. gauge
Lubrication	Forced feed
Lubricating oil capacity	27 gals.

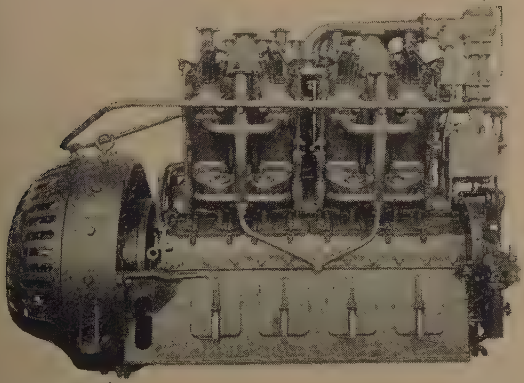


Fig. 11. V-type, 8-cylinder, 200-b.h.p. maximum, 550-r.p.m., Gasoline-electric Unit Designed for Traction Purposes

The fundamental factors of its performance at the time this article was prepared were:

Number of hours locomotive has been in actual service till March 1, 1924	437.70
Number of gallons of fuel oil used	1542.15
Number of gallons of lubricating oil used	120.50
Kilowatt-hours developed	9423.00
Time lost due to failure	8.17 hours
Cost of fuel oil per kw-hr.	0.864 cents
Cost of lubricating oil per kw-hr.	0.63 cents

It is also possible to build a 600-h.p. locomotive with two 300-h.p. units operated electrically in multiple. The generators when provided with separate excitation and differential series fields will divide the load in accordance with the power delivered to the generator shaft and neither will take more load than it can properly carry.

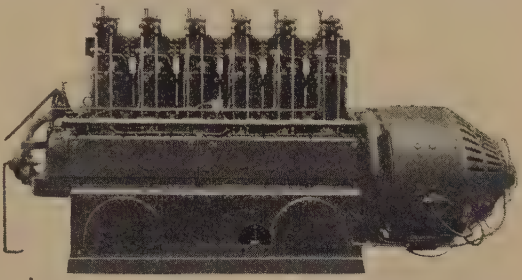


Fig. 12. Ingersoll-Rand Oil Engine and Electric Generator Developed for Railway Service

It is proposed to build locomotives using as many of these 300-h.p. units as the service demands.

Economy of the Internal Combustion Electric Locomotive

Mr. A. H. Babcock, electrical engineer of the Southern Pacific Company, in his article of April, 1923, in the Journal of the A.I.E.E. showed by a series of very carefully conducted tests that the best fuel efficiency obtainable from an oil-fired steam locomotive is 6.4 per cent while the average seldom exceeds 5.57. By that is meant that of the heat units obtainable from a pound of fuel only 6 per cent is delivered to the wheels of a locomotive. A solid fuel injection engine of the type under consideration delivers 30 per cent at the shaft and there is no difficulty of getting from 20 to 24 per cent delivered through electric transmission to the rim of the wheels. In other words, a locomotive burning the fuel in an internal combustion engine and delivering it electrically to the rim of the wheels could run four times as far with the same fuel as a steam oil-fired locomotive.

Gas-electric *vs.* Oil-electric Locomotives

The question is sometimes asked whether the oil engine or the gasoline engine is preferable for internal combustion locomotives. The case may well be stated in this way: gas engines can be commercially designed for running from 1000 to 1200 r.p.m. whereas oil engines at the present time are limited to speeds from 500 to 600.

The weight of the gasoline engine and the electric generator connected to it is therefore substantially one-half of that of an oil engine, and the first costs are correspondingly lower.

On the other hand, the price per b.h.p. delivered for oil is substantially one-fifth that of gasoline. For industrial service, where the first cost is a serious consideration but the amount of fuel per day is not, and in powers up to about 200 h.p., the gasoline or alcohol burning engine is likely to have a satisfactory field. The same applies to 60-passenger rail motor car units. However, when the building of a main line freight or passenger locomotive is under consideration, where fuel becomes a considerable item, the oil locomotive is the logical prime mover, since the cost of operation, irrespective of operator but including first cost and depreciation, is for gasoline about double that of oil equipments.

Electrification and the Internal Combustion Electric Locomotive

It is quite within reason to assume that within 10 to 20 years the steam locomotive, the efficient servant of the past, will have given way to electrification on the one hand, and to the internal combustion locomotive on the other hand, where conditions for electrification are not the most suitable.

In large city terminals like New York, Chicago, Philadelphia, Boston, etc.; in the Rockies where water powers are available and regeneration a distinct benefit; in the Alleghenies where the coal fields could be used for superpower stations, and not only cheaper power be furnished to locomotives by electric transmission, but the locomotives themselves be relieved of carrying such a large amount of coal for their own propulsion—in all such locations, electrification will be the ultimate solution, but electrification means a large expenditure of capital which under economic pressure is not freely spent until such time as the service demands it.

An oil-electric locomotive can be built at about two to two and a half times the price of a steam locomotive, but will be capable of operating at nearly 24 hours per day as compared to the 8 or 10 hours now obtained from a main line locomotive. The first cost of such a unit is not necessarily prohibitive, in view of the possibility of doing the work of at least two steam locomotives with one oil-electric locomotive, particularly when it is considered that by the use of an oil-electric locomotive the distance between division terminals can be increased from 150 to 500 miles or more, thus doing away with extra roundhouse facilities. Furthermore, an oil-electric locomotive can practically use its water supply over and over again and does not require the placing of watering service stations as frequently as steam service demands.

The question is frequently asked what would happen to our liquid fuel oil supply if the railroads of this country were to use it for locomotives. This may best be answered by saying that just because the supply of fuel oil is limited it certainly ought to be used in internal combustion engines and not burned under boilers, as is being done on the Pacific Coast and on vessels. There is every reason why machinery ought to be designed so as to utilize its fuel to its fullest extent; and assuming that the oil supply is limited, the following paragraph will show that we can obtain more power from coal by dry distillation and internal combustion engines than by burning it under boilers.

One ton of coal will produce, when burned in a locomotive (on the basis of one b.h.p. for 10 lb. of coal), 200 h.p.-hr. If the same quantity of coal were dry distilled, it would give:

(1) 160 lb. of liquid fuel (23 gal.) equaling 250 h.p.-hr.
(2) 66 per cent semi-coke
(3) 5400 cu. ft. of gas (800 B.t.u.)
(4) 66 lb. of coal tar.

These last three factors if burned under a *stationary boiler* would give 850 h.p.-hr.

Thus we can obtain from one ton of coal about five times the power that we can get by steam direct.

Furthermore, we would have as by-products:

44 lb. of lubricating oil
2.6 lb. of paraffin wax
20 lb. of ammonia sulphate.

In other words, a municipality could by dry distilling its coal furnish cheap gas for heating purposes, furnish power for electric light, sell ammonia for fertilizer, and sell the liquid fuel for internal combustion oil engines. Such an installation would build a smokeless city and furnish all the oil we require for traction purposes; and if the worst comes and our coal supply is exhausted, we still can plant prickly pears in the tropics and get alcohol for fuel.

The cross-section of a locomotive is limited by tunnels, bridges, and structure clearances to a definite allowable maximum. It is therefore of prime importance that the engines and generators constituting the power plant in such a locomotive should be of the lightest weight per horse-power and should occupy the minimum possible space.

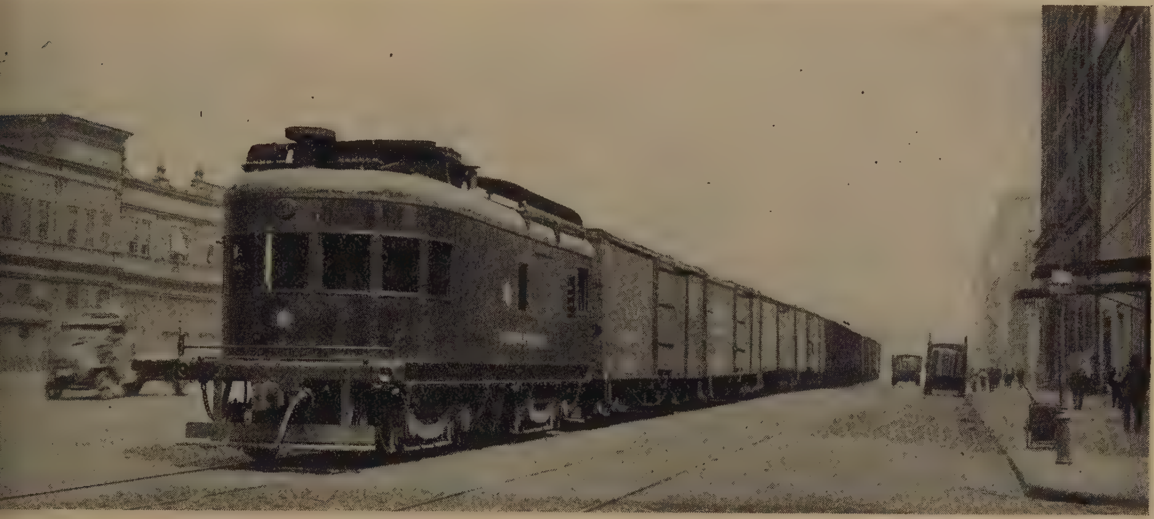


Fig. 13. Sixty-ton Oil-electric Locomotive Hauling Eight-car train in the New York Central Railroad Yards, New York City

Comparing small multi-cylinder engine nits with those of larger size, the smaller nits can be run at a greater rotative speed vithout exceeding safe piston speeds owing o their smaller reciprocating masses. This ncrease of speed effects also a reduction in he weight of the electric generators and such igh-speed units can therefore be built for a ower weight per horse power than the larger izes.

An oil engine of 300-h.p. has a thermal fficiency of about 30 per cent and this efficiency would be only slightly increased if the ngine were of ten times that capacity. No objection can therefore be raised to the use of the smaller size of unit from the standpoint of efficiency.

Electric transmission permits of utilizing the combined powers of the smaller units irrespective of their location in regard to the driving wheels. Multiple power units on main-line locomotives also insure the reliability of operation so essential in railroad service.

It is therefore perfectly logical to concentrate on the design of a power unit of relatively small size with the intention of using multiples of these units for locomotives of greater capacity. Such a design is best suited for mass production as it insures low first cost, ease of replacement of interchangeable parts, and consequently low maintenance, all of which features have been demonstrated in the automobile industry. By using multiples of these units in such numbers as are best suited to any particular size of locomotive, the standardization of locomotives is made possible.

The Design of Small High-reactance Transformers

By R. H. Chadwick and D. W. Merchant

Transformer Department, Ft. Wayne Works of General Electric Company

In the designing of transformers for certain types of service, more than the minimum of reactance is deliberately included for the purpose of protecting the transformer itself or the device which it serves. This greater reactance in transformers of the smaller sizes is in many cases obtained most economically by the use of magnetic shunts. A description of this departure from conventional transformer design is given in the following article together with an explanation and example of its method of calculation.—Editor.

General Considerations

In transformers of power sizes any amount of reactance ordinarily required by service conditions may be readily obtained by a suitable proportioning of the number of turns and size of core, combined with a judicious arrangement of the groups of coils and spacing between groups. This is true even for the relatively high reactance transformers required in synchronous converter substations.

However, in small transformers, the so-called specialties, it is frequently more economical to obtain high leakage reactance by the use of magnetic shunts, or stacks of steel punchings between the coils. There are two reasons for the different condition in small transformers: first, the fact that the reactance required may be much higher; and second, the fact that a sufficient increase in number of turns to produce high reactance is relatively more costly in a small transformer.

One example of a transformer that requires very high reactance is the filament transformer used for lighting the filament of a large radio transmitting tube. The resistance of the filament when cold is so much less than the hot resistance that it amounts almost to a short circuit on the transformer, and it is necessary to limit the current to prevent mechanical damage to the filament while it is warming up.

Then there are an unlimited number of possible requirements for limiting current in transformers used with household devices, such as door bells, toys, furnace regulators. Usually, Underwriters' regulations, or some other consideration, make it necessary definitely to limit the energy which such a transformer can take from the line with a dead short circuit on the secondary.

One advantage in the use of magnetic shunts in such cases is the greater reliability with which the reactance of small, "freak" designs can be calculated. Thus by neglecting several factors and using a relatively simple formula, it is possible to calculate the reactance close enough so that at the most only a change of one or two pieces of iron will be required when the transformer comes to test. In other words, the calculations are at least of as high an order of accuracy as the factory work of shearing the laminations for the shunts.

The method and formulas developed in the following paragraphs have been used successfully over a wide variety of sizes. They possess the virtue of being simple and easy to manipulate in routine factory designing. They neglect the effects of exciting current and iron losses, and have been found to meet requirements with exciting currents as high as 50 per cent. When the exciting current is greater than 50 per cent some consideration should be given to its effect in increasing the primary current.

Method of Calculation

The first step in the design is to calculate the core and winding without regard to the reactance requirements, except leaving sufficient space for the magnetic shunts between coils, as shown in Figs. 1 and 2. These diagrams show the shell-type arrangement, but the discussion applies equally well to the core type. Unless there is some special mechanical reason for using the arrangement in Fig. 1, that in Fig. 2 should be followed because it requires only half as much material for the shunts. For a series-multiple primary, the arrangement in Fig. 2 can be used equally as well as that in Fig. 1.

The dimensions of the magnetic shunts are determined from the following considerations:

The length, h, of the laminations making up the shunts is equal to the height of the stack of the main core.

The width, C, of the laminations is equal to the width of the wire space in the main core punching minus the total gap required.

$$\left.\begin{array}{l}\text{For Fig. 1: } C=S-g\\ \text{For Fig. 2: } C=S-2_g\end{array}\right\} \qquad (1$$

g is derived from the equation

$$g = \frac{4.5\,N_S\,I_S}{B} \qquad (2)$$

where

N_S = number of secondary turns
I_S = secondary current in amperes
B = allowable flux density in lines per square inch in shunts. (Peak value of sine wave.)

It should be kept in mind that I_S is the secondary current under the conditions for which the shunts are being calculated and is not necessarily the rated load current.

The factor B should be made as high as possible without reducing the permeability to a value approaching unity. For a general average it may be considered good practice to make B about 10 per cent greater than the normal flux density in the main core.

Having determined g, the width of the shunt laminations is determined from equation (1).

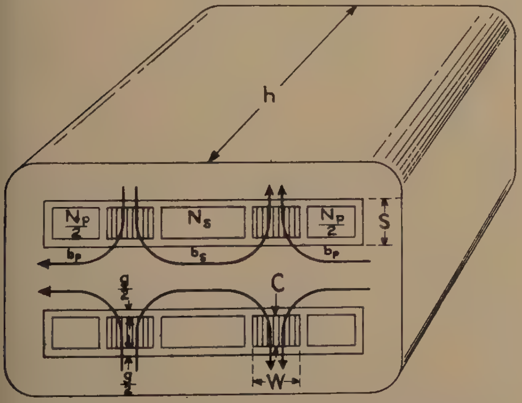


Fig. 1. Diagram Showing the Arrangement of Magnetic Shunts and Coils in a High-reactance Transformer of the Shell Type

This gives the length and width of the aminations. It remains only to determine he height of the stack, which is calculated rom the following equation:

$$W = \frac{10^8\,g\,E_{XSE}}{35.4\,f\,N_S^2\,I_S h} \qquad (3)$$

where in addition to the quantities already defined

W = height of stack of each shunt
E_{XSE} = total equivalent reactance volts required in terms of the secondary
f = frequency in cycles per second.

The factor E_{XSE} must be determined from he conditions set forth in each problem. If the shunts are to be designed to limit the short-circuit current to a definite value, then I_S is the short-circuit current in the secondary, and at this current the total open-circuit secondary voltage must be absorbed by the resistance and reactance of the transformer itself. If E_0 is the open-circuit secondary voltage, and R_S the total equivalent resistance expressed in terms of the secondary, then E_{XSE} and $I_S R_S$ added vectorially must absorb all of E_0 or

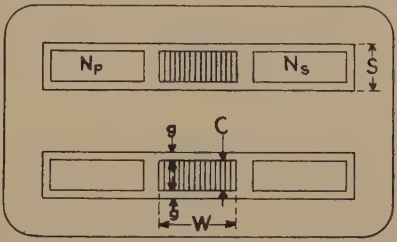


Fig. 2. The Design Here Shown is Similar to That in Fig. 1, Except That it Requires Only Half as Much Shunt Material

$$E_{XSE} = \sqrt{E_0^2 - (I_S\,R_S)^2} \qquad (4)$$

If the shunts are designed for some condition other than short circuit, E_{XSE} must be so chosen as to absorb all of E_0 not taken up by the remainder of the circuit, including the resistance of the transformer itself.

If X_L and R_L are respectively the reactance and resistance of the load circuit external to the transformer, then

$$E_{XSE} + I_S X_L = \sqrt{E_0^2 - (I_S\,R_S + I_S\,R_L)^2} \qquad (5)$$

It is seen that equation (4) is a special case of equation (5), with X_L and R_L equal to zero.

Example

The example to be used is a transformer for lighting the filament of a radio tube, as shown in Fig. 3, where the filament when hot takes 52 amp. at 22 volts.

Therefore the hot filament resistance $= \frac{22}{52} = 0.423$ ohms. It is also specified that the cold resistance of the filament is 10 per cent of the hot resistance.

Therefore the cold filament resistance = 0.0423 ohms. The filament regulating rheostat has enough resistance to absorb two volts in the secondary. Although the rheostat is placed in the primary it may be considered as if it were in the secondary and having a resistance equal to $\frac{2\text{ volts}}{52\text{ amp.}} = 0.0385$ ohms.

The requirements to be met are that when the filament is hot the rated voltage and current will be supplied, and when the filament is cold the current will not be over 100 amp.

The primary is to operate on a 110- or 220-volt 60-cycle circuit.

Then an assumption of the secondary open-circuit voltage must be made which in this case is 30.5. With the data given a transformer is designed, leaving some space for the plugs between the primary and secondary coils. The design has 144 turns on the primary, and 20 on the secondary, the core stack being $4\frac{3}{4}$ in. high and having a window of $1\frac{1}{16}$ in. by $4\frac{7}{8}$ in. for the wire. The $1\frac{1}{16}$ in. is in the direction of the building of the coil. The primary resistance is 0.422 ohms and the secondary resistance is 0.00878 ohms.

Then:

Total secondary load resistance (hot) $=0.423+0.0385=0.4615$ ohms

Total secondary load resistance (cold) $=0.0423+0.0385=0.0808$ ohms

Equivalent secondary resistance of transformer

$$=0.00878+0.422\left(\frac{20}{144}\right)^2$$

$=0.0169$ ohms.

Let B max. $= 90 \times 10^3$.

From equation (2)

$$g=\frac{4.5 \times 20 \times 100}{90 \times 10^3}=0.1 \text{ inch gap.}$$

Equation (1)

$C=1.0625-2\ (0.1)$

$=0.8625$ inch; width of laminations of magnetic plugs (Fig. 2).

In order to calculate the other dimension, W, of the magnetic plugs, the value of E_{XSE} must be determined, the value being for a cold filament.

Equation (5), assuming the value X_L to be negligible,

$$E_{XSE} = \sqrt{(30.5)^2-(100\times0.0169+100\times0.0808)^2}$$

$=28.9$ volts.

Therefore equation (3)

$$W=\frac{10^8\times0.1\times28.9}{35.4\times60\times(20)^2\times100\times4.75}$$

$=0.717$ inch height of stack of plugs.

Therefore, the plugs in Fig. 2 will be made of 14-mil steel $4\frac{3}{4}$ in. long, 0.863 in. wide, and 0.717 in. stack. These plugs limit the current to 100 amp. when the filament is cold. The transformer being designed for 22 volts, 52 amp. secondary full load, a check must be made to determine whether the correct open-circuit voltage was assumed to meet the full-load or hot filament condition of the problem.

This check is made by using equation (5). The right-hand part of the equation

$$\sqrt{E_0^2-(I_S\,R_S+I_S\,R_L)^2}$$

when calculated for the values given for a hot filament should approximately equal the value of E_{XSE} for a hot filament.

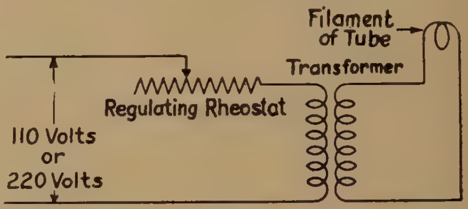


Fig. 3. Diagram of Connections of a High-reactance Transformer for Lighting the Filament of a Large Radio Transmitting Tube

Therefore

$$\sqrt{E_0^2-(I_S\,R_S+I_S\,R_L)}$$

$$=\sqrt{(30.5)^2-(52\times0.0169+52\times0.4615)^2}$$

$=17.6$ volts.

Then from equation (3)

$$E_{XSE}=\frac{35.4\times60\times20^2\times52\times0.717\times4.75}{10^8\times0.1}$$

$=15.05$ volts.

The values do not check which shows that the open-circuit voltage assumed at the beginning is incorrect. By again using equation (5), assuming X_L to be negligible, the open-circuit voltage can be determined,

$$E_0=\sqrt{E^2_{XSE}+(I_S\,R_S+I_S\,R_L)^2}$$

$$=\sqrt{15.05^2+(52\times0.0169+52\times0.4615)^2}$$

$=29.1$ volts.

The calculations should then be corrected for an open-circuit voltage of 29.1, but in this case the primary turns would be 151, maintaining the same number of turns on the secondary. The transformer is designed for either 110 or 220 volts, consequently the primary must have an even number of turns so 150 turns will be used. The secondary open circuit voltage will be 29.3. The corrected primary resistance is 0.439 ohms.

Then:

Equivalent secondary resistance of the transformer

$$=0.00878+0.439\left(\frac{20}{150}\right)^2$$

$=0.01658.$

Then check both sides of equation (5)

$$E_{XSE}+I_S X_L=\sqrt{E_0^2-(I_S R_S+I_S R_L)^2}$$

$$15.05=\sqrt{29.3^2-(52\times 0.01658+52\times 0.4615)^2}$$

$$15.05=15.5$$

The right-hand half of the equation is 3 per cent higher than the left-hand part but is close enough to give the desired results.

If great accuracy were required it would be necessary to recalculate the dimensions of the magnetic shunts for the new ratio, and perhaps to make several trials; but in this problem, where a regulating rheostat is used, and the limiting current is arbitrarily chosen, no further refinement is worth while.

Derivation of Equations

Equations (2) and (3) are derived as follows:

$$b=b_P+b_S$$

where

b = flux density in shunts, lines per sq. cm. at any instant

b_P = number of lines per sq. cm. due to primary ampere-turns at any instant

b_S = number of lines per sq. cm. due to secondary ampere-turns.

In the following are made three assumptions which experience has shown are permissible for the accuracy usually sought. It is assumed that all the leakage flux passes through the magnetic shunts; that the reluctance of the steel portion of the leakage path in both the main core and the shunts is negligible compared with the reluctance of the gap; and that the leakage factor generally required in calculations involving air gaps can here be neglected because of the shortness of the gap.

Let N_P = number of turns in primary

i_P = instantaneous value of primary current in amperes

i_S = instantaneous value of secondary current in amperes

Then, from the fundamental equation for a magnetic circuit, assuming all reluctance in the air gap:

For Fig. 1

$$b_P=\frac{4\pi \frac{N_P}{2} i_P}{10\,g}=\frac{4\pi\,N_P\,i_P}{10\times 2\,g}$$

$$b_S=\frac{4\pi\,N_S\,i_S}{10\times 2\,g}$$

For Fig. 2

$$b_P=\frac{4\pi\,N_P\,i_P}{10\times 2\,g}$$

$$b_S=\frac{4\pi\,N_S\,i_S}{10\times 2\,g}$$

But $N_S\,i_S=N_P\,i_P$ since exciting current is neglected.

Therefore $b_S=b_P$.

Assuming sine wave, changing to crest value of flux, r.m.s. current, and dimensions in inches,

$$B_P=B_S=\frac{4\pi\,N_S\,I_S\times 1.41\times 2.54}{10\times 2\,g}=\frac{4.5\,N_S\,I_S}{2\,g}$$

The total density in the shunts in lines per square inch, crest value, with current expressed in r.m.s. value, is

$$B=B_P+B_S=2\,B_S=\frac{4.5\,N_S\,I_S}{g}$$

$$g=\frac{4.5\,N_S\,I_S}{B} \qquad (2)$$

Let

E_{XP} = leakage reactance volts in primary

E_{XS} = leakage reactance volts in secondary

$E_{XPS}=E_{XP}$ reduced to equivalent secondary

E_{XSE} = total equivalent reactance volts in terms of secondary $=E_{XS}+E_{XPS}$

A = area of air gap in square inches, still assuming that all the reluctance of the leakage path is in the gap.

Then

$$E_{XS}=4.44\,f\,N_S\,B_S\,A\times 10^{-8}$$

from the standard equation for voltage generated in any coil by an alternating flux surrounding it; and

$$E_{XP}=4.44\,f\,N_P\,B_P\,A\times 10^{-8}$$

But

$$E_{XPS}=E_{XP}\times\frac{N_S}{N_P}\text{ and }B_S=B_P$$

Therefore

$$E_{XPS}=4.44\,f\,N_P\,B_S\,A\times 10^{-8}\left(\frac{N_S}{N_P}\right)=4.44\,f\,N_S\,B_S\,A\times 10^{-8}=E_{XS}$$

and

$$E_{XSE}=E_{XS}+E_{XPS}=2\,E_{XS}=2\times 4.44 f\,N_S\,B_S\,A\times 10^{-8}$$

Using a space-factor of 0.885 for scale and space between the laminations of the shunts, which is about correct for 0.014-inch steel:

$$A=Wh\times 0.885\times 2$$

(The factor 2 is introduced by the fact that the flux passes through two shunts in parallel.)

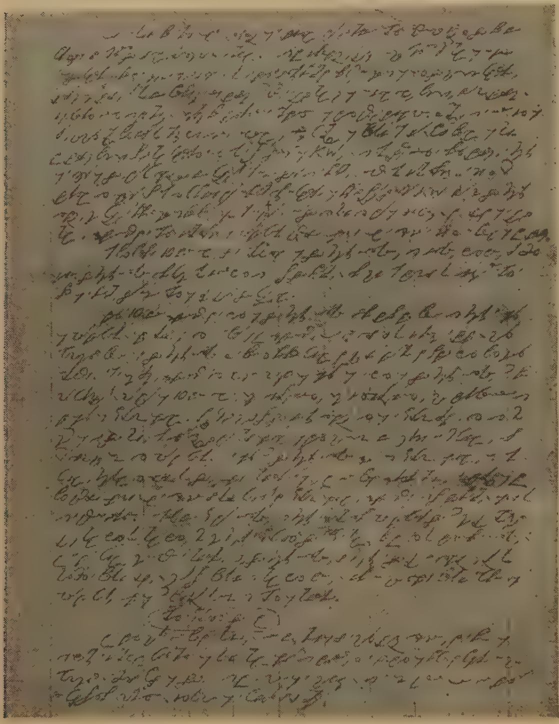
Therefore

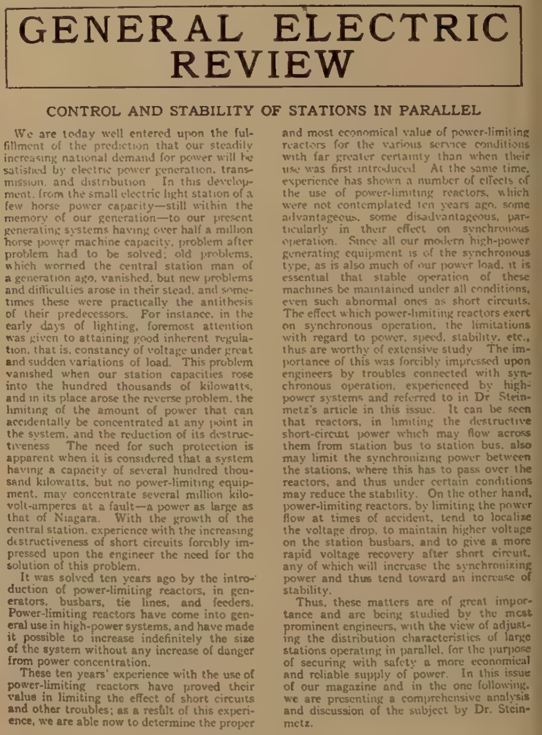
$$E_{XSE}=2\times 4.44 f\,N_S\,\frac{4.5\,N_S\,I_S}{2\,g}\times Wh\times 0.885\times 2\times 10^{-8}=\frac{35.4\,f\,N_S^2\,I_S\,Wh}{10^8\,g}$$

$$W=\frac{10^8\,g\,E_{XSE}}{35.4\,f\,N_S^2\,I_S\,h} \qquad (3)$$

A REMINISCENCE OF STEINMETZ

With the coming of large and complex power systems came the practice of installing power-limiting reactors. This revision in the scheme of operation gave rise to a new set of conditions affecting the stability of connected synchronous machines; and to furnish a better insight into the behavior of a system under these conditions, Dr. Steinmetz made an exhaustive mathematical analysis for the A.I.E.E. This paper we reprinted in our issues of August and September, 1920.





GENERAL ELECTRIC REVIEW

CONTROL AND STABILITY OF STATIONS IN PARALLEL

We are today well entered upon the fulfillment of the prediction that our steadily increasing national demand for power will be satisfied by electric power generation, transmission, and distribution. In this development, from the small electric light station of a few horse power capacity—still within the memory of our generation—to our present generating systems having over half a million horse power machine capacity, problem after problem had to be solved; old problems, which worried the central station man of a generation ago, vanished, but new problems and difficulties arose in their stead, and sometimes these were practically the antithesis of their predecessors. For instance, in the early days of lighting, foremost attention was given to attaining good inherent regulation, that is, constancy of voltage under great and sudden variations of load. This problem vanished when our station capacities rose into the hundred thousands of kilowatts, and in its place arose the reverse problem, the limiting of the amount of power that can accidentally be concentrated at any point in the system, and the reduction of its destructiveness. The need for such protection is apparent when it is considered that a system having a capacity of several hundred thousand kilowatts, but no power-limiting equipment, may concentrate several million kilovolt-amperes at a fault—a power as large as that of Niagara. With the growth of the central station, experience with the increasing destructiveness of short circuits forcibly impressed upon the engineer the need for the solution of this problem.

It was solved ten years ago by the introduction of power-limiting reactors, in generators, busbars, tie lines, and feeders. Power-limiting reactors have come into general use in high-power systems, and have made it possible to increase indefinitely the size of the system without any increase of danger from power concentration.

These ten years' experience with the use of power-limiting reactors have proved their value in limiting the effect of short circuits and other troubles; as a result of this experience, we are able now to determine the proper and most economical value of power-limiting reactors for the various service conditions with far greater certainty than when their use was first introduced. At the same time, experience has shown a number of effects of the use of power-limiting reactors, which were not contemplated ten years ago, some advantageous, some disadvantageous, particularly in their effect on synchronous operation. Since all our modern high-power generating equipment is of the synchronous type, as is also much of our power load, it is essential that stable operation of these machines be maintained under all conditions, even such abnormal ones as short circuits. The effect which power-limiting reactors exert on synchronous operation, the limitations with regard to power, speed, stability, etc., thus are worthy of extensive study. The importance of this was forcibly impressed upon engineers by troubles connected with synchronous operation, experienced by high-power systems and referred to in Dr. Steinmetz's article in this issue. It can be seen that reactors, in limiting the destructive short-circuit power which may flow across them from station bus to station bus, also may limit the synchronizing power between the stations, where this has to pass over the reactors, and thus under certain conditions may reduce the stability. On the other hand, power-limiting reactors, by limiting the power flow at times of accident, tend to localize the voltage drop, to maintain higher voltage on the station busbars, and to give a more rapid voltage recovery after short circuit, any of which will increase the synchronizing power and thus tend toward an increase of stability.

Thus, these matters are of great importance and are being studied by the most prominent engineers, with the view of adjusting the distribution characteristics of large stations operating in parallel, for the purpose of securing with safety a more economical and reliable supply of power. In this issue of our magazine and in the one following, we are presenting a comprehensive analysis and discussion of the subject by Dr. Steinmetz.

On the left is a reproduction of the actual lead-pencil "notes" of Dr. Steinmetz referred to in this article. On the right is their transcription as printed on the editorial page of the August, 1920, *G. E. Review*

Two incidents in connection with the earlier installment remain sharp in the recollection of the writer, and because they revealed several characteristic traits of the Doctor they may engage the interest of our readers.

A shortage of time in which to submit proof for the Doctor's examination and approval necessitated a trip to his camp on the Mohawk River, a few miles above Schenectady, where he was busily engaged in preparing another convention paper as shown on the front cover of this issue. Though having retired to this seclusion to avoid being disturbed, he immediately interrupted his work and, in that gracious and accommodating manner for which we loved him, turned to the fourteen pages of proof and read them word for word. Particularly remarkable was his "scanning scrutiny" of the many formulas in some of which he detected an error in a mathematical sign here, an exponent there, and a subscript elsewhere, with exactly the same readiness as would one of us notice a typographical error in the word "txe" (the). Astounded, the writer asked him how he did it, and well remembers his reply: "Why, they simply didn't look right."

The other incident was in connection with the leading editorial which had been prepared for that issue on the theme of the Doctor's article and which on this visit was shown to him for comments.

All was not well with the editorial, but the writer was not told of this directly. Instead, he was guided to perceive it by degrees while being treated to a personally-conducted mental tour through the maze of phenomena involved. In place of criticism which might hurt one's feelings, this was Dr. Steinmetz's way of correcting those who were willing to learn. But his assistance did not stop there. In his private system of shorthand he quickly wrote out what he said were notes that might be of help in revising the editorial. When these had been transcribed by his secretary, Miss Rhein, they proved to be so connected and clear-cut an exposition of the entire subject that with but minor changes they were adapted directly for use as the editorial.

E. C. SANDERS

Electric Arc Welding on the Steam Locomotive

By W. M. B. Brady

Arc Welding Specialist, Chicago Office, General Electric Company

Welding in locomotive repair work is rapidly becoming one of railroads' indispensable tools. When it is ealized that of the 65,000 locomotives in service 18 per cent are usually undergoing repairs, and that during he past five and one-half months over 300,000 repair jobs have been made on this number of locomotives, he possibilities of this comparatively new tool will be better appreciated. The following article has been written to spread more widely a knowledge of the superior economy and utility of electric arc welding for quickly making reliable repairs and building up worn surfaces. The information given is of a horoughly practical nature, and confirmed by many photographs of the work done by the electric arc ogether with records of the short time and low costs of this method of welding.—Editor.

In the manufacture and repair of steam ocomotives, the demonstrated merits of the lectric arc process renders unnecessary the iving of consideration to other methods. This is due to four basic characteristics of he direct-current arc method of welding, as ollows:

(1) Extreme local application of heat, which practically eliminates all contraction and expansion difficulties
(2) Low cost of producing the heat
(3) No preheating required and but a small amount of preparatory labor
(4) Efficiency of the weld.

The illustrations in this article show the pplication of electric arc welding to various arts of locomotives; including the fire box, lexible stay-bolts, cylinders, frame, motion arts, wheels, and much of the sheet-metal vork.

Fire-box Welding

Fig. 1 illustrates a fire box dismantled reparatory to applying a Duplex automatic toker. The engine is to have a new fire ox and a new combustion chamber, both f which will be renewed at this time. The hotograph shows the side sheet removed, a ortion of the crown sheet out, the combusion chamber partially dismantled, as well s the radial stays and fire-box stay-rods nd complete mud ring. This is on a Pacific ype locomotive which has been in service en years previous to these renewals. The ismantling required two men for eighteen ours.

Fig. 2 shows the assembly work continued o the stage where the back head is prepared nd ready for applying the automatic stoker. The back-head plates are not as yet bevelled or arc welding.

Fig. 3 is an inside view of the back sheet ompletely welded with the duplex stoker n place. The seam around the three sides equired 22 ft. of welding, using 20 lb. of $\frac{5}{32}$-in. electrode at 150 amp. This work required one operator for 12 hours.

Fig. 4 illustrates the back sheet with the duplex stoker in place. The inserted sheet, after being placed in position, was tacked at two-foot intervals. Then the top seam was welded completely across, using the step method; each six inches of the seam was formed by beads welded on a slope of approximately 45 deg. (slant), then alternating with the next six inches of seam having beads on the opposite 45 deg. (slant). This welding procedure is adopted so that when the seam is subjected to a strain the weld will not break along a straight line because the alternate sloping of the waves of deposited metal distributes the strains, deflecting them from the line of weld. The plate is $\frac{5}{8}$ in. thick, requiring 22 ft. of welding on the outside sheet, including welding around the two duplex stoker ports. This consumed 25 lb. of $\frac{5}{32}$-in. electrode, using 150 amp. The time required was 12 hours.

Fig. 5 is a view of the upper part of the combustion chamber showing eight feet of butt weld on the crown sheet of $\frac{3}{8}$-in. boiler plate, requiring 12 lb. of $\frac{5}{32}$-in. electrode at 150 amp. The time taken was eight hours. The crown sheet was prepared with the bevel on the top side and welded through the steam dome, with a fillet or wash weld applied to the fire side, as illustrated.

The photograph also shows the flues and superheater flues electric arc welded. Care must be exercised to see that the copper ferrule (between the flues and flue sheet) is set back in the head at least $\frac{1}{32}$ in., thus to prevent copper from working toward the fire side of the flue sheet and under the head of the flue for the reason that copper is not weldable by metallic steel electrodes and because a protrusion of the copper ferrule will prevent a good weld being made. Before the welding is started, it is necessary that all oil and grease be removed between the flue head and the flue sheet. This can be accomplished

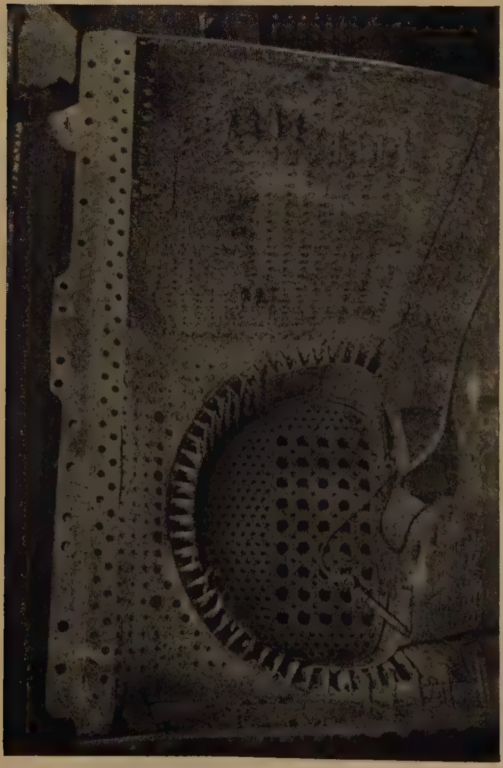


Fig. 1. Locomotive Fire Box Dismantled

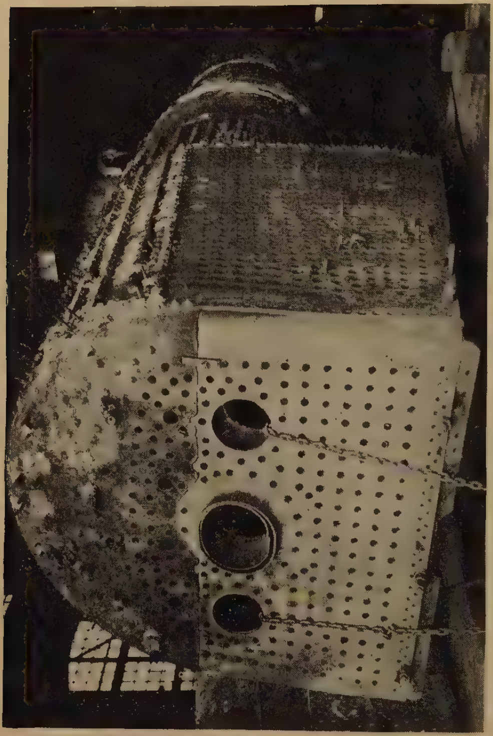


Fig. 2. Back Head Prepared for Applying Automatic Stoker

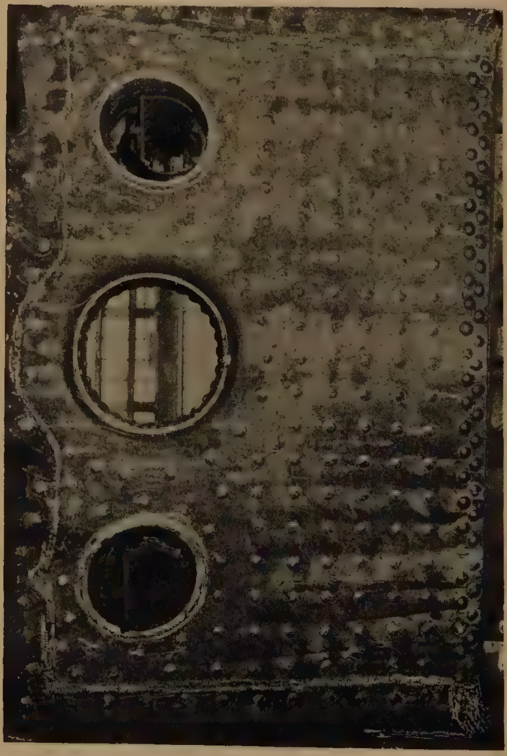


Fig. 3. Inside View of Fire Box Back Sheet

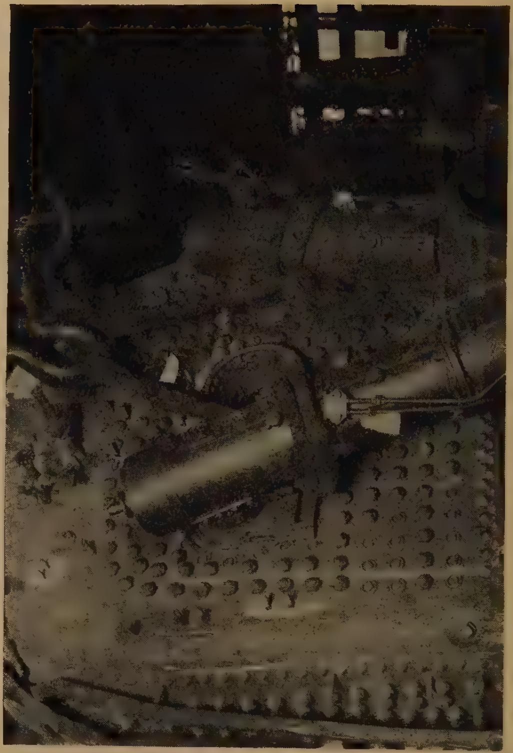


Fig. 4. Outside View of Fire Box Back Sheet

by heating the engine in the shop to steam pressure or running the engine one trip. Before the welding is started the flues should be sand-blasted. In welding the operator should begin welding at the bottom of the flue and work up on the opposite side and meet at the top with a small over-lap. (The welding should never be done from top to bottom.) This method applies to both the small flues and superheater flues. The applied metal should not exceed the height of the flue bead and should never extend over the top center of the flue bead as a pocket will thus be formed in which fire cracks may develop.

Flexible Stay-bolts

Fig. 6 shows a new locomotive shell in the process of manufacture, containing a total of 1417 flexible stay-bolts. Flexible stay-bolts consist of three principal parts; namely, the sleeve, the bolt, and sleeve cap. The sleeve is first welded to the outer fire-box plate, then the bolt is inserted and the sleeve cap screwed firmly in place. Approximately 125 of these flexible stay-bolt sleeves can be welded by a competent operator in an eight-hour day, using $\frac{5}{32}$-in. electrodes and 150 amp. An order was received recently by one of the locomotive companies to provide 125 locomotives, each with a complete set of 1417 flexible stay-bolts.

Fig. 7 is a close-up view of a locomotive shell showing flexible stay-bolt sleeves arc welded and bolts inserted (sleeve cap removed). The procedure is similar to that of welding flues; namely, welding the circle in two halves, beginning at the bottom, proceeding half way around, stopping at the top, then beginning again at the bottom, proceeding up the other side, and meeting at the top.

Fig. 8 illustrates a locomotive fire-box shell showing flexible stay-bolt sleeves arc welded with bolts inserted and caps in place. To replace a broken or defective stay-bolt, the cap is removed, making the bolt readily and easily accessible for renewal. Also as the name indicates, the bolt affords a flexible staying of the surfaces and in case of bolt breakage the welded sleeve allows only a minimum amount of steam and water leakage.

Cylinders

Figs. 9, 10, 11, and 12 are of four stages in repairing a broken cast-iron locomotive cylinder. This particular job required a total of 144 hours, in which time 300 lb. of $\frac{5}{32}$-in. electrode was deposited with 150 amp. current. The casting required a total of 128 studs.

Studs and labor to install	$25.00
Dismantling	28.00
Both rings	35.00
Machining rings in place	8.00
Electric power	22.00
Electrode material	30.00
Welding labor	108.00
Total	$256.00

The broken cast-iron locomotive cylinder was first chipped, studded, and the valve chamber ring put in place. This ring, which is made up of a steel forging, has been machined and fitted to the valve chamber. The forging and machine work on the ring is often done even before the broken locomotive has been received in the shop. From the roundhouse or wherever the engine has been inspected and welding recommended as the remedy, the engine number and the nature and location of the break is sent to the locomotive repair shop. Immediate steps are taken to have the necessary parts repaired so that, upon receipt of the engine, the chipping and studding may immediately be undertaken and the ring set in place ready for welding. The same method of procedure is followed with the segment of the cylinder ring itself, which is shown missing. These parts are practically carried in stock ready for immediate use on demand and no time is lost in fitting them to the cylinder.

It might be interesting to note that the cost of a new cylinder for a locomotive of this type would be $1100 without considering the time lost while waiting for the cylinder and installing it. It may also be interesting to know that a certain railroad has reclaimed 167 cylinders similar to this during the past two and one-half years; and previous to this time records show that 250 cylinders were welded, making a total of 417 reclaimed cylinders placed in service without one failure.

Frame

Fig. 13 is of a side frame repaired in place by the insertion of a forged steel section. This repair was made by cutting out the faulty section by means of the gas cutting torch and a new section forged to fit. In making the upper weld, the frame itself was chipped to a chisel edge, the point of which reached to the flat top of the forged piece, leaving a gap of ¼ inch; then one

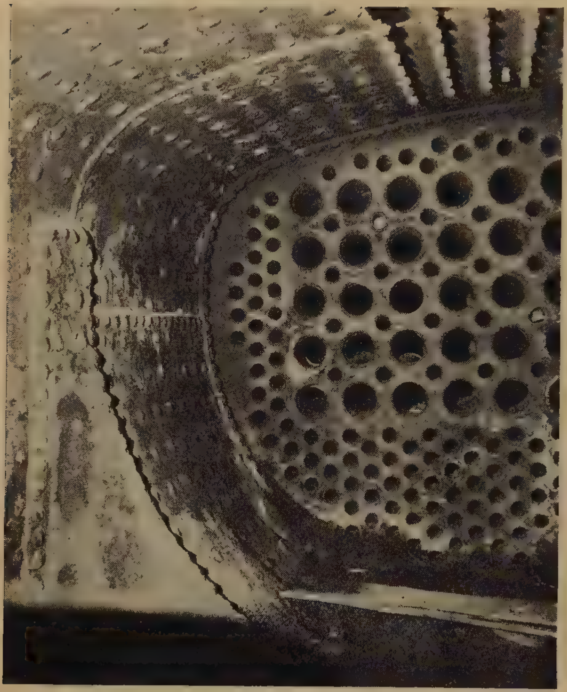


Fig. 5. Upper Half of Locomotive Combustion Chamber

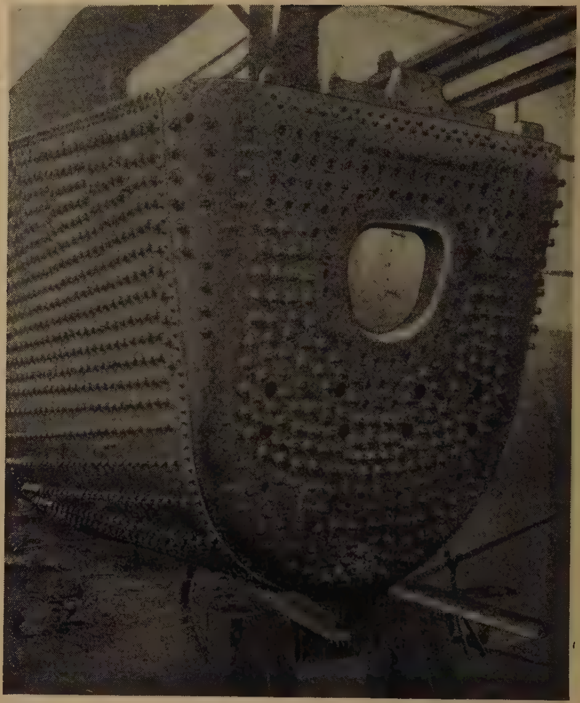


Fig. 6. Locomotive Shell Showing Flexible Stay-bolts

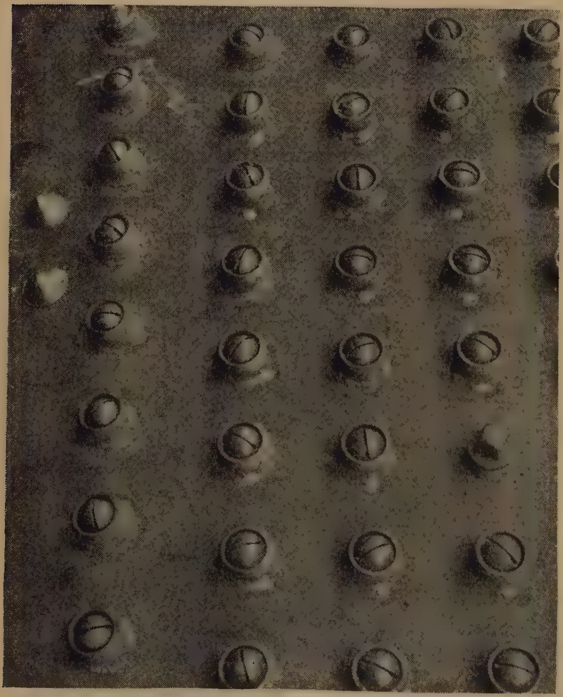


Fig. 7. Close Up View of Flexible Stay-bolts

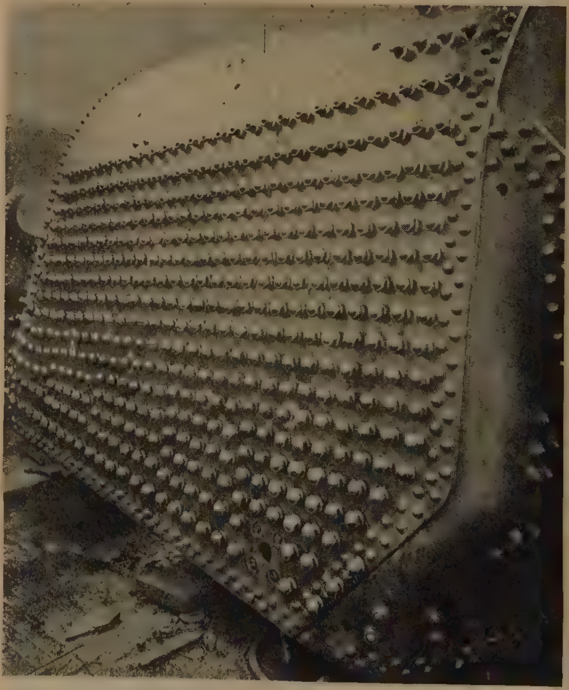


Fig. 8. Flexible Stay-bolts Arc Welded with Bolts Inserted and Caps in Place

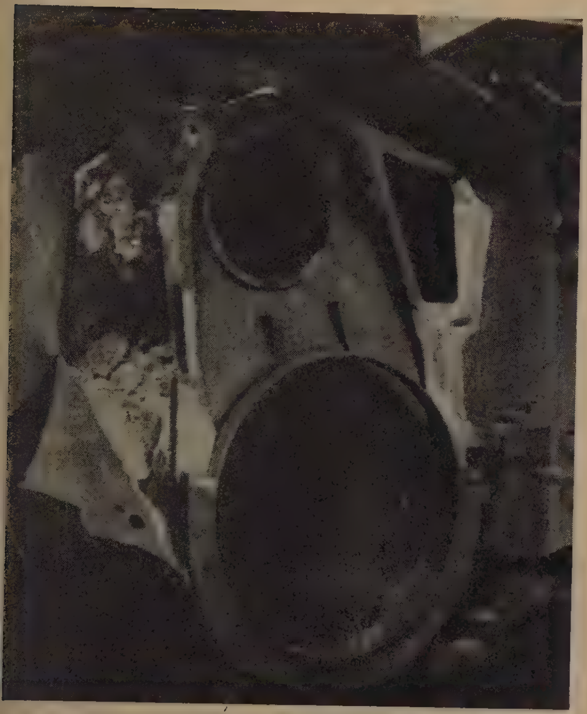


Fig. 9

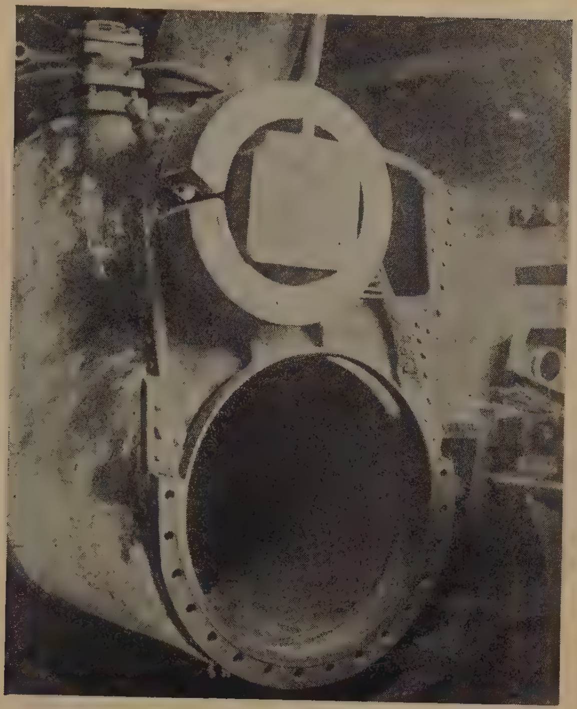


Fig. 10

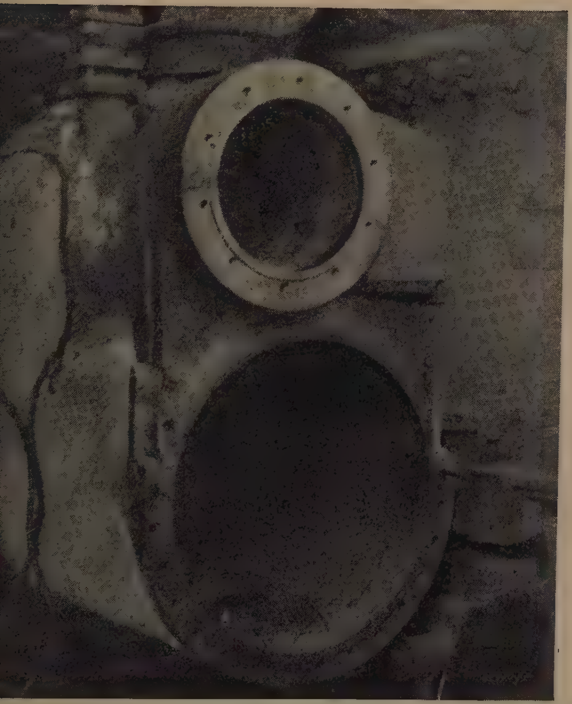


Fig. 11

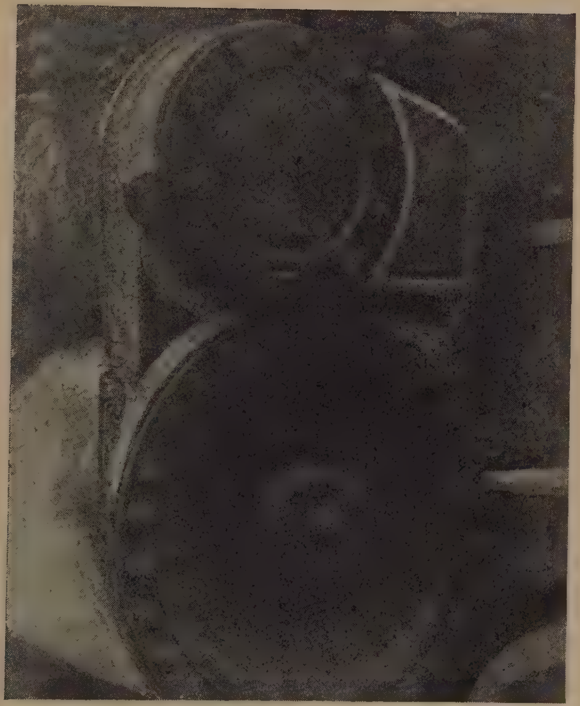


Fig. 12

Various Stages in the Repair of a Broken Cast-iron Locomotive Cylinder

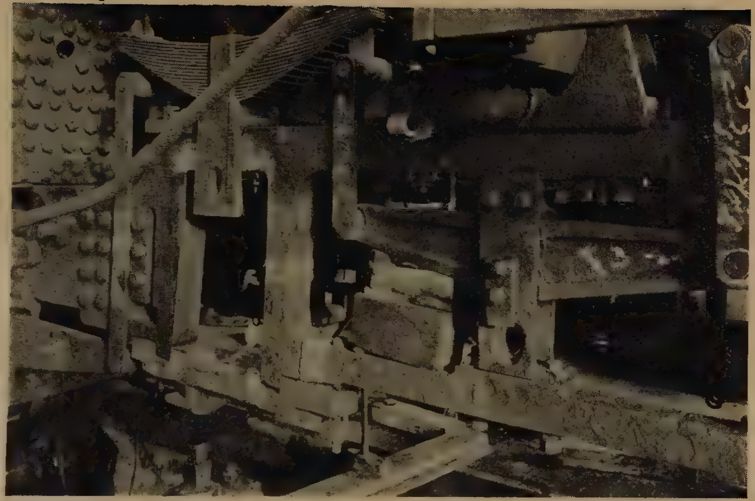


Fig. 13. Locomotive Frame Welded Without Dismantling Engine

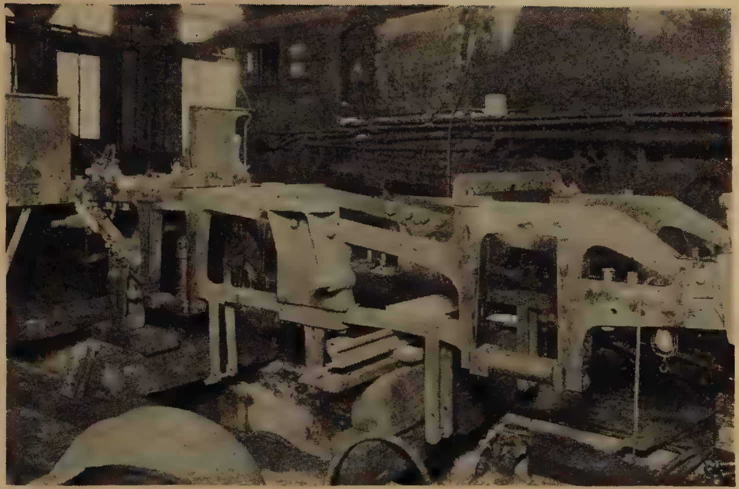


Fig. 14. Locomotive Frame Completely Dismantled

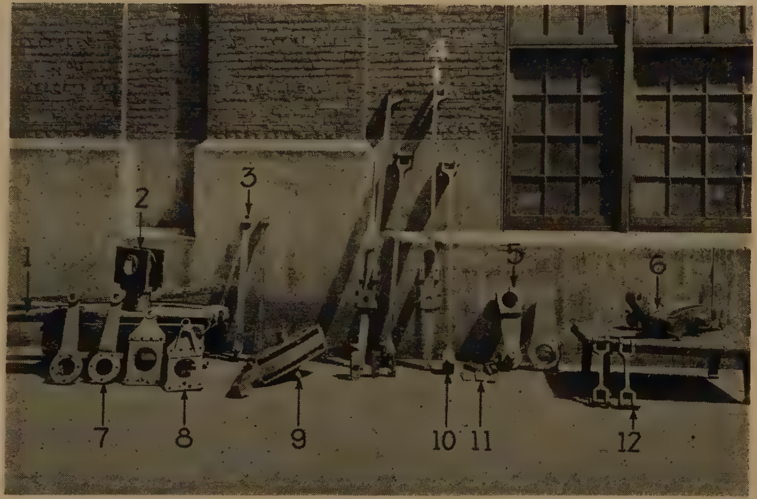


Fig. 15. Disassembled Set of Worn Locomotive Motion Parts

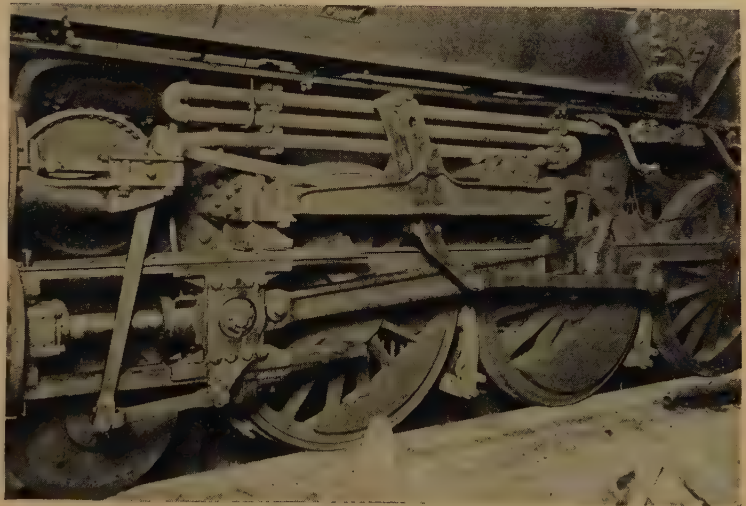


Fig. 16. Reassembled Set of Repaired Locomotive Motion Parts

bead was welded to close the opening and unite the upper part of the forging to the frame. The process was continued by layer on layer in crescent form and working out. This work can be done by one operator working on one side at a time; or by two operators, one on either side of the frame, working simultaneously. The lower weld is made by "V"-ing to a chisel point both the frame and the forged piece, with a space of ¼ inch between. This space is then filled up with a bead run vertically, beginning at the bottom and finishing at the top, thus joining the two pieces. Proceeding as before the first bead is welded over and continued outwards until the "V" is completely filled up. The operator must do all the welding with the electrode pointing perpendicular to the work.

Two men welded this frame in 10 hours, totalling 20 hours of welding labor, using 35 lb. of $\frac{5}{32}$-in. electrode at 165 amp. Two hours was required to forge the added piece in the blacksmith shop and eight hours additional for the machinist to prepare the piece, shaping and chipping the block, making a total of ten hours preparatory labor. The only dismantling of the locomotive was the dropping of a pair of wheels at the fracture.

Fig. 14 shows a locomotive frame stripped of the boiler, wheels, and motion parts prior to receiving general repairs at which time advantage is taken to apply welding although this dismantling is not necessary for the purpose. This photograph shows a number of places on the frame where welding is employed to compensate for wear which has taken place in service. The illustration shows only one side of the frame, and with the exception of the broken part at the extreme right has a duplicate amount of welding on the other side of the frame.

At the extreme left is shown a brake post bracket reinforcing, which work required two hours welding for each bracket. Just above that is shown a corner built up on the frame brace, requiring one pound of $\frac{5}{32}$-in. electrode, which was deposited in one-half hour, using 150 amp. The brake post near the center has been padded to compensate for wear, requiring one-half pound of electrode material and 15 minutes labor. The worn spots on the lower part of the frame have been built up by laying in pieces of ¼-in. plate and applying a fillet weld around the edge. These pieces are welded in 15 minutes each. The break in the frame shown at the right was repaired by "V"-ing the crack from both sides, leaving a gap ¼ inch, then joining the frame beginning at the bottom and welding to the top, then continuing layer on layer in crescent form, working out. On this frame a ⅜-in. plate was placed at the bottom, shaped to fit the corner and welded around all four sides. Eight hours was required to deposit approximately 15 lb. of $\frac{5}{32}$-in. electrode, using 150 amp. The total welding labor came to 13½ hours. This frame has a 3 by 4-in. cross section and is for a light-weight engine.

Motion Parts

Fig. 15 shows a complete set of motion parts entirely disassembled and spread out for identification. The following lists the place which is subject to wear on each piece and which is built up by the arc welding process:

No. 1. 1¾-in. padding full length of guide on each side, requiring 16 hours for the set of four.
No. 2. Cross-head—padding up worn surface on inside of guide, also plugging and reboring the eight bolt holes.
No. 3. Combination lever—plugging holes and padding on worn surface.
No. 4. Radius bar—plugging pin holes and remachining, building up worn sliding surface and welding inside of jaw, also welding in new case-hardened steel bushing.
No. 5. Crank arm—welding up keyway.
No. 6. Link—plugging holes, padding up post seat, and adding metal to worn undersize surfaces.
No. 7. Lift shaft iron—padded and rebushed.
No. 8. Cross-head plate—plugging holes and reboring for new exact fit, also padding union link connection hole.
No. 9. Link—padding worn undersize surfaces, plugging and reboring holes.
No. 10. Eccentric rod—welding worn surface, plugging and reboring holes for new fit.
No. 11. Motion pins—adding metal to worn surfaces.
No. 12. Union link—plugging holes and padding inside surface.

Total time for complete set 36 hours, requiring 75 lb. of $\frac{5}{32}$-in. electrode, and using 150 amp.

Fig. 16 shows the motion parts repaired by the electric arc process and in position on the locomotive.

Miscellaneous

Fig. 17 is of a cast steel locomotive back cylinder head. In the manufacture of cylinder heads, it is often found after considerable machining has been done that the casting is exceptionally spongy, which condition would permit steam to leak at the

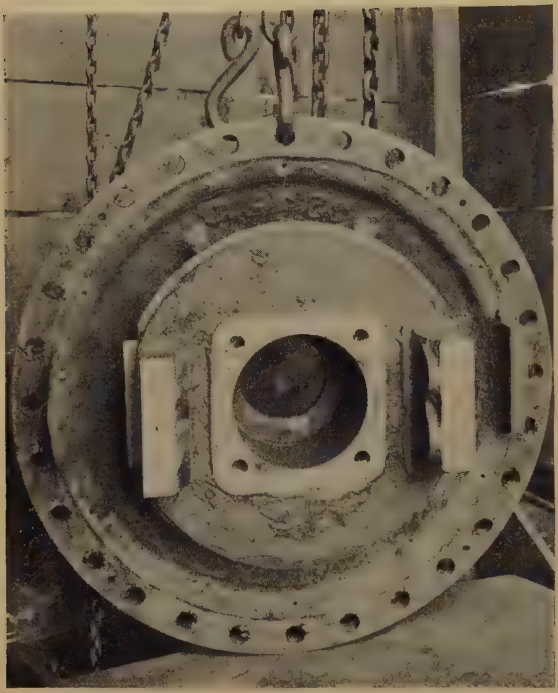


Fig. 17. Back Cylinder Head with Spongy Metal in Bore Replaced by Arc

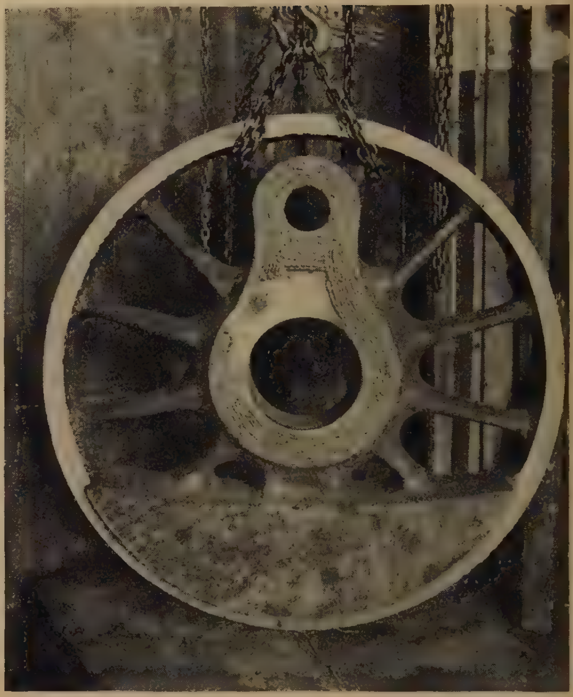


Fig. 18. Driving Wheel with Under-sized Hub Stock, Salvaged by Arc Welding

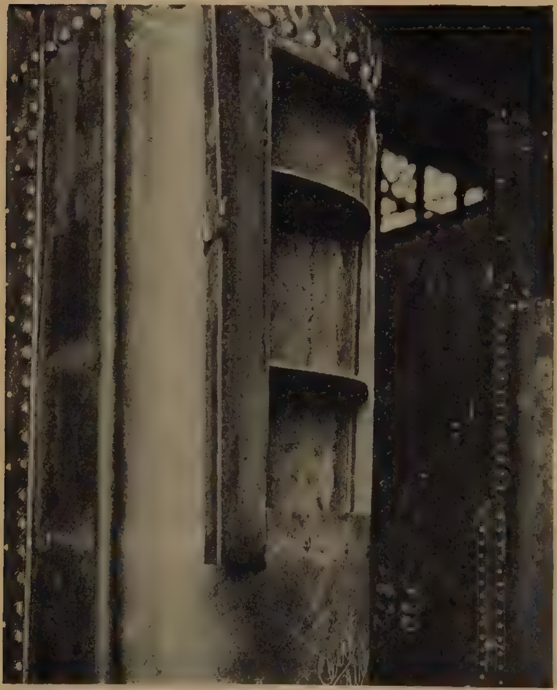


Fig. 19. Locomotive Tender Tool Box, Inside View of Electric Arc Construction

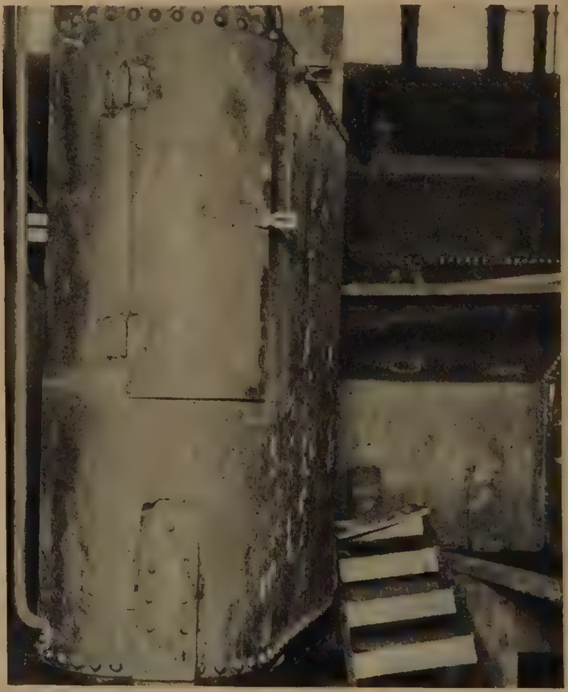


Fig. 20. Locomotive Tender Tool Box, Outside View of Electric Arc Construction

stuffing box. This photograph shows in the rear of the center bore a place where foreign matter has been removed to a depth of approximately 1¼ by 1½ inch, and the cavity rebuilt with the electric arc. This work required two and one-half hours, and 5 lb. of $\frac{5}{32}$-in. electrode at 150 amp.

Fig. 18 is of a locomotive wheel scant of stock at the hub. This undersized new wheel was salvaged by depositing 90 sq. in. of welding ¼ inch high at the hub and crank pin. The building-up process required two hours, and used $\frac{5}{32}$-in. electrodes at 150 amp. The added metal allows for machining and thus reclaims the wheel.

Fig. 19 is of a locomotive tender tool box, the complete electric arc welding of which requires 22 ft. of seam welding. It is one of a pair, each requiring four hours of welding labor and consuming 8 lb. of $\frac{5}{32}$-in. electrode at 150 amp. The plates are $\frac{5}{16}$-inch thick.

Fig. 20 shows the tool box door closed with both hinges and latch securely fastened by electric arc welding.

Fig. 21 illustrates an assortment of sand domes at a locomotive plant, each of which necessitated 40 ft. of seam welding. One seam on each dome can readily be distinguished at the bottom of the domes; the second seam near the top of the dome has been ground off and when the complete finishing touches have been made and the dome painted, the seam cannot be detected. The 40 ft. of seam per dome was welded by one operator in eight hours, using 151 lb. of ⅛-in. diameter electrode at 125 amp. The sand domes are made of ¼-in. plate.

Fig. 22 shows a locomotive tender in service after being completely welded by the electric arc welding process. This illustrates, as far as we know, the first locomotive tender which has been completely electric arc welded. The completed tank is not only strong but has the added advantage of freedom from leakage. It was built at the West Springfield Shops of the Boston & Albany Railroad. The sheets are joined at the corners by welding them securely to tank angles. This is a satisfactory method as the welding can be done rapidly at reasonable cost and the strength of the joint is in excess of that usually obtained by the riveted type of construction. The side plates are butt welded, and tank braces and splash plates are securely welded to the sheets, and the whole construction results in a watertight tank of good appearance. The safety appliances and tank lugs are riveted. The tender tank is 26 ft. long, 10 ft. wide, and 5 ft. 2 in. high, having a capacity of 8000 gallons of water and 12 tons of coal, and is used with a Pacific type locomotive for passenger service. The tender tank has now been in service for more than four years.

Fig. 23 is the front view of a single-operator, portable arc welding outfit of the self-excited, constant-energy, 200-amp. *intermittent* service type for metallic electrode welding.

Fig. 24 is the portable semi-automatic arc welder best suited for locomotive welding where the operation equals or exceeds one half-hour of welding at one time on a given job, and is adaptable for frame work and those seams in the fire box which can be reached with a 15-ft. lead.

Fig. 25 is a front view of a single-operator, portable arc welding outfit of the self-excited, constant-energy, 200-amp. *continuous* service type for metallic electrode welding. The arc is easy to start and easy to maintain, which are features that all operators desire. All regulation of the current is accomplished by a twist of the handwheel on the generator. Another exclusive design feature is the self-adjusting reactor which automatically steadies the arc under all welding conditions. Waste-packed bearings insure ample lubrication, will not spill oil if the set is tipped when being moved, and will last for years. Any value of current can be obtained between 75 and 300 amp. with an infinite number of steps between these limits. The exact current needed for the job can thus be obtained. The outfit can be used with short or long leads and will thus handle jobs close at hand or over a thousand feet away. It is especially adapted for supplying power to automatic arc welders for continuous welding.

This type of welder is designed for smooth and rapid deposition of metal with thorough penetration. This means more metal deposited per hour and more footage per day. It is capable of delivering 24-hr. service, day after day.

Fig. 26 shows by means of curves the general cost relations between the electric arc welding and acetylene welding of boiler plates. These curves are necessarily general and approximate. However, several points can be readily rechecked from

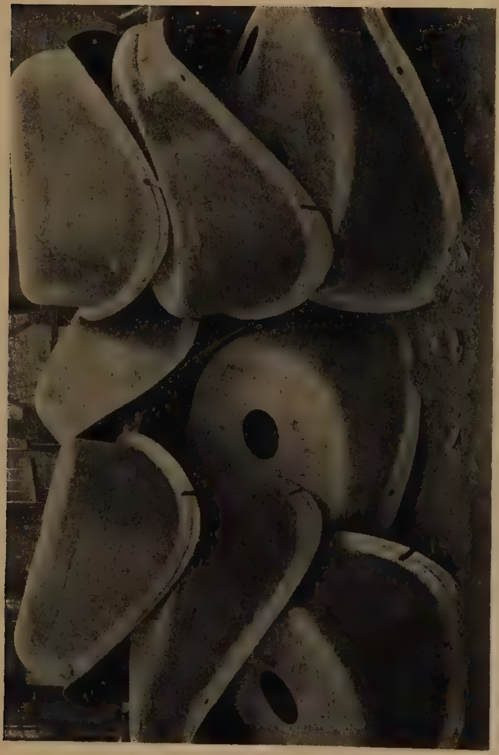


Fig. 21. An Assortment of Electric Welded Locomotive Sand Domes

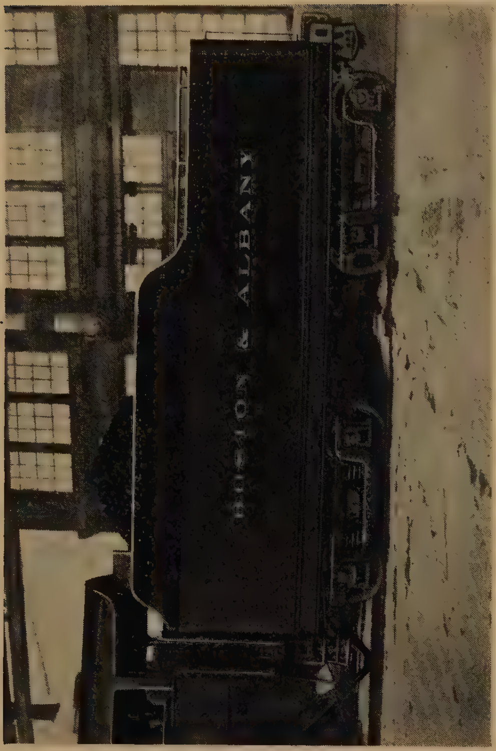


Fig. 22. Locomotive Tender, 100 Per Cent Electric Arc Construction

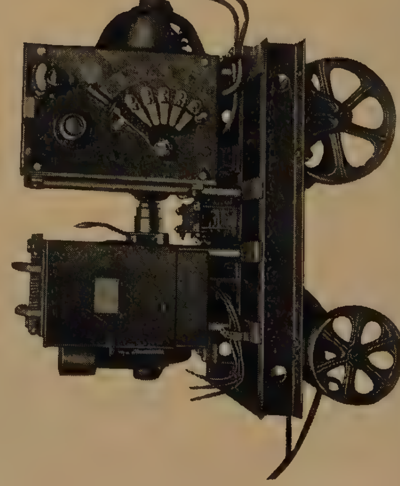


Fig. 23. Portable Electric Arc Welder, Capacity 200 Amp. Intermittent

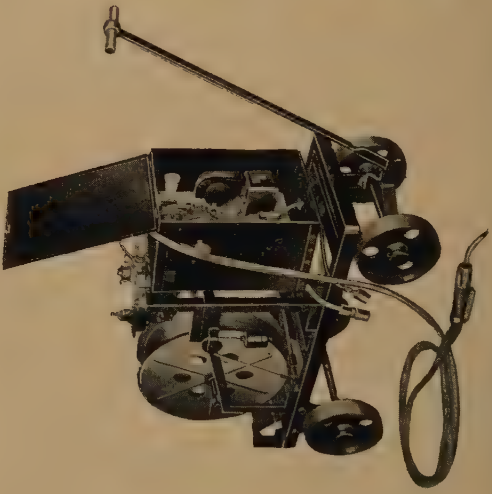


Fig. 24. Portable Semi-automatic Arc Welder

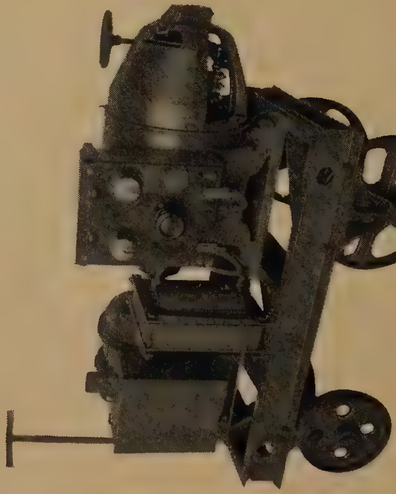


Fig. 25. Portable Electric Arc Welder, Capacity 200 Amp. Continuous

the data submitted in the foregoing. For example:

Rechecking, Fig. 4

Plate ⅝ in. thick, 22 ft. in 12 hr., consuming 25 lb. of electrode, assuming labor at $0.78 per hour, electrodes at $0.10 per pound, and power $0.04 per kw-hr.

Labor—12 hr. at $0.78	$9.36
Electrode—25 lb. at $0.10 lb.	2.50
Power—6-kw. input at $0.04 per kw-hr. for 12 hr.	2.88
Total welding cost	$14.74

$14.74 ÷ 22 ft. = 67 cents per linear foot.

The curve gives the cost for ⅝-in. plate at 68 cents per linear foot.

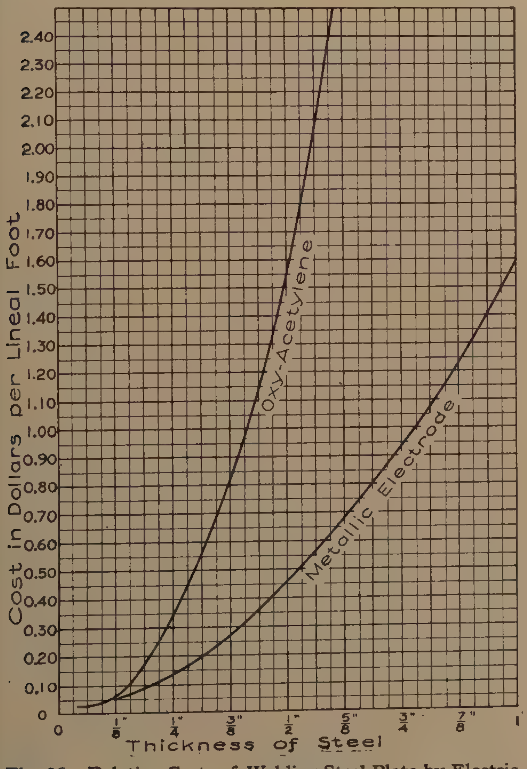


Fig. 26. Relative Costs of Welding Steel Plate by Electric Arc Versus Oxy-acetylene Process

Rechecking Fig. 19

Plate 5/16 in. thick, 22 ft. in 4 hr. requiring 8 lb. of electrode.

Labor—4 hr. at $0.78	$3.12
Electrodes—8 lb. at $0.10 per lb.	0.80
Power—6-kw. input at $0.04 per kw-hr. for 4 hr.	0.96
Total welding cost	$4.88

$4.88 ÷ 22 ft. = 22 cents per linear ft.

The curve gives 21 cents for 5/16-in. plate.

Local conditions including price of labor, electrodes, and power will vary the cost per linear foot but the curve in Fig. 26 can be used for estimating purposes.

As another means of comparison the following data may be used:

The calorific value of acetylene is 1555 B.t.u. per cu. ft.

Therefore

1 cu. ft. of acetylene and 1 cu. ft. of oxygen equals 1555 B.t.u.
1 kilowatt-hour equals 3413 B.t.u.
1 cu. ft. of acetylene costs approximately 2½ cents
1 cu. ft. of oxygen costs approximately 1½ cents
1 kw-hr. costs approximately 2 cents
4 cents worth of oxygen and acetylene gives 1555 B.t.u.
4 cents worth of electric power gives 6826 B.t.u.
or
2000 B.t.u. cost 5.2 cents when produced by oxygen and acetylene
2000 B.t.u. cost 1.2 cents when produced by electricity.

Remarks

Caulking tools should be discarded for a better job is done by chipping out and actually rewelding leaky or defective portions of work.

All seams where extreme tensile strength is required should be double welded.

In welding, the ground connection should be securely made. Too often welders depend upon mere weight for this connection by raising and placing the ground plate or stub end of the return cable under their work.

Where it is possible to complete the weld in one layer, it is good policy to do so, as the heat is confined at the point of welding which results in deeper penetration and largely eliminates the formation of oxide.

When electrodes become cherry red while working it is an indication that the size of electrode is too small for the amount of current being used, thus causing a poor weld.

Meetings, conferences, and publications on the subject of arc welding should be encouraged for they broadcast ideas, methods, and experiences, thus eliminating trade secrecy. The progress and advancement so far has been a material help, but a continuance of united efforts will set forth established practices which in turn will become standard methods, thus elevating welding from an art to an exact engineering science.

Studies in the Projection of Light

PART XIII

THE DOUBLE PARABOLOIDAL MIRROR

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

The cost of a searchlight mirror is an important item that must be kept in mind in the design; and, as the author points out, certain optical surfaces are easier to form than others. Plane and spherical surfaces are largely self-forming, while the paraboloid possesses to a certain extent this same tendency. Where the back optical surface of a mirror is largely ground by machinery, the paraboloid would therefore probably be more economical than the optically correct co-paraboloid, but if any large amount of the finishing process is hand work then the latter form of surface is to be preferred. The method of adjusting two paraboloids, as the front and rear surfaces of a glass mirror, is based on the information gained in developing the co-paraboloid. An empirical formula relating the basic features of the design is developed in this article, and data are given for a number of mirrors that conform in size and thickness to present mirror practice. Two mirrors are designed, one correct at 40 deg. and the other correct at 50 deg. A chart is given on which the actual thickness of any finished mirror may be plotted, and by noting the deviation between the plotted curve and the ideal curves the surface errors may be evaluated and used in the computation of the beam characteristic. This is done in several examples and the reduction in beam intensity is found to agree with the original photometric test data that formed the basis of this series of Studies in the Projection of Light.—Editor.

Some Natural Optical Surfaces

The parabolic mirror used in searchlights is an article of some precision, but it is well to distinguish between the mirror of commerce and the scientific instrument of the astronomer. When a telescope having a diameter of 60 in. is built, it is a matter of international importance; technical journals and the daily press find in the new telescope a prolific source of interesting news, often of a speculative nature. The reason for the great interest displayed is primarily the rarity of large telescopes. As a contrast to this rarity, the mirror of commerce, and particularly the mirror for military use, must often be turned out at the rate of hundreds per year. In addition to the urgent demand for large quantities of mirrors in a military emergency, there is always the matter of the cost of production. For these reasons the mirrors are produced on a quantity basis, and obviously the work must be done largely by machinery and not by hand. The mirror in which we are interested is therefore a machined article, and we may profitably inquire into its characteristics and see how it conforms to the requirements.

In the manufacture of optical lenses or mirrors there are three surfaces that are in some measure self-forming. First in order of natural accuracy is the plane surface. In recent years the grinding of glass and metal gauges and optical surfaces has reached a high state of perfection. It is a rather common occurrence to hear of a new commercial or technical use for "optical flats," as the glass disks are called. A wavelength of green light is half of one millionth of a meter, but optical flats are made with less variation from perfection than this. In principle the manufacture of optical flats is extremely simple, but in practice there is required a high degree of skill. The principle of grinding is as follows: three fairly flat surfaces *a*, *b*, and *c* are ground together in all combinations; that is, *a* against *b*, *a* against *c*, and *b* against *c*. As this cycle of operations is repeated, all three surfaces show a natural tendency to become flat and the degree of flatness is seemingly limited only by the skill and patience of the workman.

A second natural surface is the sphere; but while a spherical grinder on a spherical glass surface may give a true spherical form there will possibly be a variation from the desired radius. Thus the natural accuracy of the spherical surface is one degree less than the natural accuracy of the plane surface.

The third natural surface is the paraboloid. Such a surface cut by a meridian plane gives a parabolic section, and furthermore, any parallel cutting plane will give an exactly similar section. Thus a parabolic gauge or grinding strip made to fit a meridian section will fit a paraboloidal surface in any plane parallel to the meridian. This may not be a manufacturing possibility, but it indicates a theoretical method for mutually justifying a grinding form and an approximately paraboloidal surface. Thus, if both form and surface are worn by the grinding, then a lateral movement of the form combined with a rotation of the surface will ultimately bring both surfaces into full contact in all positions, which is possible only when they are both parabolic in outline. There are many linkages that will guide a grinding pad in a parabolic curve, and numerous patents have been granted for paraboloid grinding machines. Not all of these are commercially successful, but they indicate a certain degree of ease in attaining a parabola; and hence the paraboloid is one of the three natural surfaces, and it is to be preferred for manufacturing to any aspheric or non-conical surface. This greater natural precision is the reason we have double-parabolic mirrors rather than the better optical combination of parabola and its exact optical mate, the co-parabola.

In the grinding and particularly the polishing of an aspheric surface there is always a strong tendency for the surfaces to form into concentric waves. This tendency must be combated at all stages of the process, and where any precision is required the final touch is hand work. If the amount of hand finish is small the double paraboloid would seem to be the logical quantity article, but if the hand work is extended through any great part of the process it would seem that the co-paraboloid would better repay the effort. The selection of back surfaces is therefore tied up with a number of factors that are not to be overlooked because they are not strictly in the realm of optical design.

The Double Paraboloid

Granting the commercial desirability of making glass mirrors with both surfaces paraboloidal, the question arises, how shall we select the two curves so as to arrive at the best optical results? Let us first set down the obvious conditions to be met and then proceed to satisfy them in what seems to be the best manner. The conditions are:

(1) A central thickness of glass, T_0, sufficient for mechanical strength.
(2) A limiting thickness at the edge of the mirror set by the thickness of the available supply of plate glass, and by the allowable weight for the finished mirror.
(3) A balancing of the optical errors so that the focal positions of various mirror zones will lie within a short space upon the optical axis.
(4) The mirror zones that are most valuable in producing high central beam intensity should be given most weight in balancing the optical errors.

The general rule is to make the central thickness, T_0, somewhere between two and four per cent of the focal length, the greater thickness being used for the smaller diameter mirrors.

There are certain limitations to the thickness of plate glass used in the manufacture of mirrors. As an example of the reality of this limitation, a number of years ago a manufacturer accepted an order for a hundred or more Mangin mirrors, but on account of the great thickness of plate glass required it was found to be impossible to fill the order, and the more expensive parabolic mirror had to be furnished instead. Several rough and fine grinding processes are performed after the blank has been molded into approximate form, and nearly half of the thickness is removed by this grinding. It is therefore necessary to keep within limits in the specifications of thickness of the finished article.

The acceptance tests of a mirror often include a "sun test." The mirror is pointed directly at the sun and smoke is blown across the image of the sun formed at the focal point. The better the mirror the smaller will be the diameter of the neck of the spindle of reflected rays. This test is not conclusive, but it is a quick and simple one that is good for a rough indication. There is one peculiar weakness of this test that seems to have escaped attention. A mirror that has a zone of large errors may pass the test readily because the out-of-focus light is so badly scattered as to escape attention. A zone of less error might focus well enough to give a visible sun image out of position and by this test be rated as the poorer of the two. In investigating a completed mirror for the third condition previously stated, certain precautions must therefore be observed or the test will give erroneous results.

It has been mentioned on a number of occasions in the discussion of the formation of a searchlight beam that the divergence from the outer zones of the mirror is less than from the central zones. Also, the area of the outer zones is greater than the inner zones. As an example, the central zone from 0 to 10 deg. on a 60-in. mirror contributes 27,600,000 candles and gives a beam of 1 deg. 30 min. width. The 50- to 60-deg. zone contributes 387,000,000 candles to the central beam and has a width of only 52 min. It is therefore evident that the outer zone is of vastly greater importance and requires a better optical accuracy than the inner zones, and the point of exact optical accuracy, if only one such point is obtainable, should be near the outer edge of the mirror.

Focal Length and Focal Point of the Second Surface

The true back surface or co-paraboloid has been located only by the computation of a number of points (x_3, y_3), but in the computation of these points the angles of both the incident and reflected rays have been obtained. The bisector of these two ray-paths is the normal to the optically correct surface, and if the co-paraboloid is to be replaced by a paraboloid of correct position and curvature at a given point the two ray-paths must obviously have a common normal through this (x_3, y_3) point.

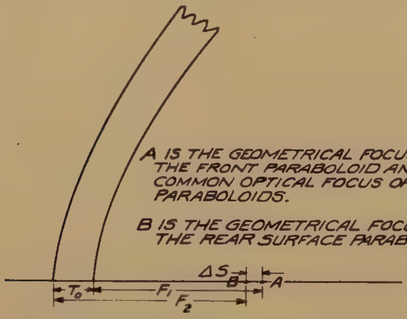

A IS THE GEOMETRICAL FOCUS OF THE FRONT PARABOLOID AND THE COMMON OPTICAL FOCUS OF BOTH PARABOLOIDS.
B IS THE GEOMETRICAL FOCUS OF THE REAR SURFACE PARABOLOID.
ΔS
B
A
T0
F1
F2

Fig. 144. This sketch illustrates the general relation between the geometrical focal lengths and focal points of a double paraboloidal mirror

Let d be the angle of the incident ray at (x_3, y_3) and f be the angle of the reflected ray, measuring from the X-axis. The angle of the bisector, or normal, is

$$\frac{a'}{2}=\frac{d+f}{2} \tag{164}$$

and we have the relation

$$y_3=2\ F_2 \tan\frac{a'}{2} \tag{43}$$

where F_2, the focal length of the back surface, differs from F_1, the focal length of the front surface, and the angle a' here used is to be distinguished from the angle a previously used for the front surface. Solving for F_2 we find the focal length of the back surface to be

$$F_2=\frac{y_3}{2\tan\frac{a'}{2}} \tag{165}$$

The vertex of this paraboloid is no longer at the origin of ordinates, but is shifted (to the left in Fig. 144) through the central thickness T_0 of the mirror. The equation of the generating parabola is

$$y_3^2=4F_2\ (x_3+T_0) \tag{166}$$

and we get

$$T_0=\frac{y_3^2}{4\ F_2}-x_3 \tag{167}$$

for the thickness of glass on the optical axis. The geometrical focal points of the two paraboloids, considered singly, differ in position by a space ΔS such that

$$\Delta S = F_1 + T_0 - F_2 \tag{168}$$

or putting

$$F_2 - F_1 = \Delta F \tag{169}$$

we have

$$\Delta S = T_0 - \Delta F \tag{170}$$

and if we know all the terms in the foregoing equations the double paraboloid is fully defined and is optically correct at the selected point (x_3, y_3). The optical errors at other points, and their influence, will be discussed later.

The front surface parabola of Fig. 144 has its focal point at A; the back surface has its geometrical focus at point B; but its optical focus, when used along with the other parabola, is at point A. This coincidence of optical foci is true for one point only, as will be pointed out in the next paragraphs.

Double Paraboloids Adjusted at Various Angles

The standard angular width from the axis is about 60 deg. for the great majority of accurate mirrors, but there is also use for accurate mirrors of greater and lesser angles. In order to cover the range of useful angles three sets of computations were made: one for 40 deg., one for 50 deg., and one for 80 deg. The points are near the edges of mirrors of 50-, 60-, and 90-deg. angles which are the ones selected as representing the range of requirements in mirror widths. By making

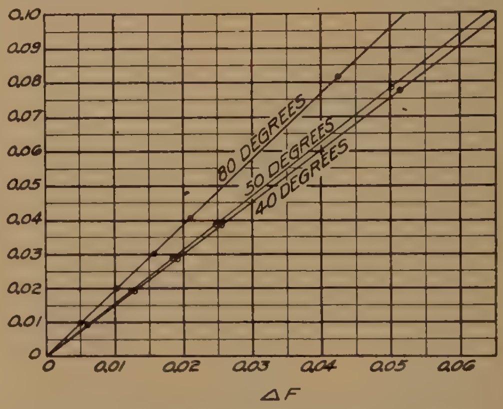


Fig. 145. The relation between the central thickness T_0 and the increment of F_2 over F_1 is apparently a straight line having a different slope for each angle of adjustment. But if the data are plotted to a larger scale each line will be found to be slightly curved and a rather complicated equation is required to express the relation of T_0 to ($F_2 - F_1$)

the double paraboloid optically correct near the edge, the net result of the projection errors for the entire mirror will be reduced to a minimum as will be demonstrated later.

There are certain standards of thickness of glass in the finished mirror. The average is about four per cent of the focal length for small mirrors and two per cent for large mirrors. There is occasional use for mirrors of more than four per cent thickness, and accordingly the computations have included values of T_0 up to 0.08 F_1.

Some computed values of $\triangle F$ are listed in Table XV along with the central thickness T_0. It should be observed that in case T_0 was required to be some particular value, as for example exactly three per cent, it would be necessary to solve equations (164) to (167) a number of times and arrive at the desired value of T_0 by a series of approximations. But it is seldom necessary to specify the central thickness closer than one part in a hundred, so that this preliminary solution for T_0 is not a matter of any difficulty.

The selection of 40, 50, and 80 deg. for the correction points was made for present requirements, but we may expect that in the future other points will be selected. To obviate the necessity of computing additional points the data on T_0 and $\triangle F$ were used to obtain an empirical expression for the relation between these factors. The choice of the form of equation is largely a matter of taste. Three types of equations were tried, and the following was found to be best for the entire body of data given in the last columns of Table XV.

It was noted that at any given angle, for example 40 deg., the following simple relation is fairly accurate:

$$T_0 = K \triangle F \qquad (171)$$

The factor K has values approximately as follows, although strictly K is not a constant for any given angle:

$a = 40$ deg., $K = 1.4860$
$a = 50$ deg., $K = 1.5454$
$a = 80$ deg., $K = 1.9042$

No simple relation between the angle a and K was found, and the following more complex expressions were adopted as being more exact and more flexible, as any angle a may be used.

$$\triangle F = \frac{T_0}{(0.125 + 0.00035a)\,T_0 + 1.4292 + 0.0545\left(\frac{a}{40}\right)^{3.1}} \qquad (172)$$

and

$$T_0 = \frac{\left[1.4292 + 0.0545\left(\frac{a}{40}\right)^{3.1}\right]\triangle F}{1 - (0.125 + 0.00035a)\,\triangle F} \qquad (173)$$

The above equations have been used to compute values of $\triangle F$ from assumed values

TABLE XV

DESIGN DATA FOR DOUBLE PARABOLOIDAL MIRRORS

Refractive Index $n = 1.52$ Focal Length $F_1 = 1$

Approx. T_0	Angle a	*SURFACES TANGENT AT			SECOND SURFACE PARABOLOID		
		x_3	y_3	$\frac{d+f}{2}$	T_0	$\triangle F$	$\triangle S$
$0.01 F_1$	40	0.1241101	0.7333731	20°1′10.20″	0.0094943	0.0063972	0.0030971
$0.02 F_1$		0.1156713	0.7388541	20°2′20.46″	0.0190741	0.0128459	0.0062282
$0.03 F_1$		0.1072098	0.7443498	20°3′30.76″	0.0286816	0.0193005	0.0093811
$0.04 F_1$		0.0987078	0.7498718	20°4′41.11″	0.0383366	0.0257758	0.0125608
$0.08 F_1$		0.0642906	0.7722258	20°9′23.03″	0.0774378	0.0518938	0.0255440
$0.01 F_1$	50	0.2096604	0.9394145	25°1′23.48″	0.0095992	0.0062271	0.0033721
$0.02 F_1$		0.2019251	0.9461728	25°2′46.11″	0.0191427	0.0124079	0.0067348
$0.03 F_1$		0.1941472	0.9529677	25°4′ 8.80″	0.0287409	0.0186132	0.0101277
$0.04 F_1$		0.1862497	0.9598681	25°5′32.41″	0.0384895	0.0249061	0.0135834
$0.08 F_1$		0.1543474	0.9877406	25°11′6.41″	0.0780736	0.0502360	0.0278376
$0.01 F_1$	80	0.6992241	1.6886384	40°1′39.94″	0.0099406	0.0052301	0.0047105
$0.02 F_1$		0.6943258	1.6991508	40°3′20.04″	0.0199601	0.0104884	0.0094717
$0.03 F_1$		0.6893933	1.7097363	40°4′58.29″	0.0300357	0.0158054	0.0142303
$0.04 F_1$		0.6844393	1.7203687	40°6′40.44″	0.0401974	0.0210953	0.0191021
$0.08 F_1$		0.6641941	1.7638185	40°13′24.04″	0.0816945	0.0427363	0.0389582

*The surfaces that are tangent are the optically correct co-paraboloid and the paraboloidal approximation which is correct optically at the angle a.

of T_0 and the agreement of the results with the original direct computation is within one part in a thousand in every case. With practically the same accuracy, which is more than sufficient for specifications and manufacturing purposes, the following can be computed over the given ranges:

Angle a, 0 to 110 deg.
Thickness T_0, 0 to $0.10F$
Refractive index 1.515 to 1.525

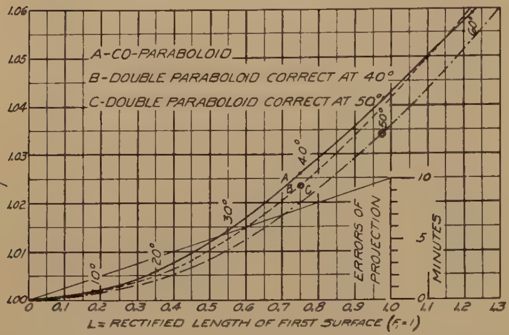


Fig. 146. The double paraboloid is thinnest in comparison with the co-paraboloid at the point of correction (marked with circles on curves *B* and *C*), and at other points there is always an excess of thickness. The angle between curves at any selected ordinate, measured on the stub scale and using the zero ordinates as a center will give a rough value for the errors of projection. This scale applies only to mirrors having a central thickness of 0.0382369 F_1, but for other thicknesses the error will go up in proportion to T_2

An error of one part in a thousand gives the following linear values in a standard 60-in. mirror.

Error in $\Delta F = 0.001 \times 0.01241 \times 25 = 0.00031$ in.
Error in $\Delta S = 0.001 \times 0.00673 \times 25 = 0.00017$ in.

These errors are less than the normal variations in a mirror made by the quantity production method, and the use of the equations will therefore introduce no new errors, although the equations themselves are empirical in nature and not capable of unlimited extension to all angles, indices, and thicknesses.

Thickness of the Double Paraboloidal Mirror

In Fig. 146 the three curves show: *A*, the thickness of the correct mirror; *B*, the thickness of a double paraboloid corrected at 40 deg.; and *C*, the thickness of a double paraboloid corrected at 50 deg. The accuracy of the latter mirrors is measured not by the closeness of their curves to curve *A* but by their approach to parallelism at any given angle a; and at the points where the curves *B* and *C* are parallel to the co-paraboloidal curve there will be no errors of projection in the double paraboloidal construction. The curves are parallel at the centers and at the selected point of correction, but at all other points there is either a deflection of the light across the axis of the beam or a divergence away from the axis. The final effect of both are identical for at working ranges the radial distance of the point of reflection is extremely small in comparison with the distance of projection.

From the center of the double paraboloid to the point of correction the mirror runs thin, and the ray which should be parallel to the axis is deflected across the axis. Beyond the point of correction the glass runs thick and the deflection is outward. The optical effect is computed, not by the variation from the correct thickness, but by the variation from parallelism with the co-paraboloidal surface. This effect will later be measured.

The Thickness Chart

The thickness curves of a set of co-paraboloidal mirrors are given in Fig. 148, where the curve of central thickness of 100 per cent was computed for glass having an index of 1.52 and T_0 equal to $0.0382369F_1$. The other curves are for mirrors of 99 to 94 per cent of this thickness. The angles given for various points on the 100-per-cent curve are values of $\frac{a+b}{2}$, or the mid-angle between the points

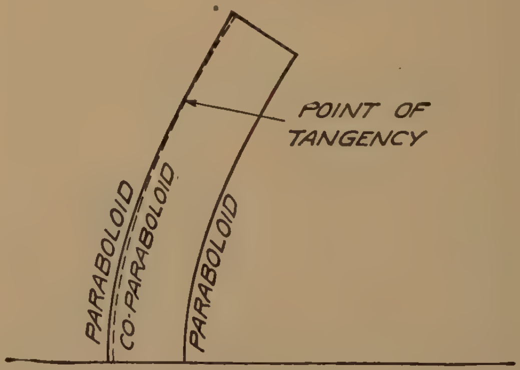


Fig. 147. In this illustration, which is to a greatly exaggerated scale of thickness, the dotted and solid curves on the back of the mirror show the relative positions of the co-paraboloid and the second surface paraboloid

of entrance and exit. The curves were made up in this form so that they could be used as a chart on which to plot micrometer measurements taken from finished mirrors. In a number of cases this has been done, and from the information so obtained it has been found possible to compute the beam characteristic as actually found by a photometric test on a defective mirror.

In Fig. 148 an angular deflection scale is laid out on the ordinate $L=1$, and it will be noted that each division is marked one minute of arc as measured about the lower left-hand corner of the web. The angular scale is here greatly enlarged, for one degree of actual angle equals only three-fourths of one minute, or a magnification of 80 to 1. It is by means of this great exaggeration of angular scale that it is possible to estimate differences as small as 0 deg. 1 min. between the direction of the correctly and incorrectly projected ray.

This particular deflection scale is for a mirror of index 1.52 and a central thickness $T_0=0.0382369F_1$. If the thickness is multiplied by a factor K the scale readings must be also multiplied by the same factor K.

Curve A, Fig. 148, which is from data on an actual mirror, shows a typical deviation from the ideal form. In making computations of beam candles from this curve it has been assumed that nearly all of the errors are confined to the second surface. There are two facts supporting this assumption. One is the greater difficulty of grinding and polishing the back surface, and the second is the fact that the computed results are in fair agreement with the test data.

In Table XVI the losses are estimated by measuring the angle between the computed curves and the test curve, Fig. 148. The action of the first surface is neglected and all

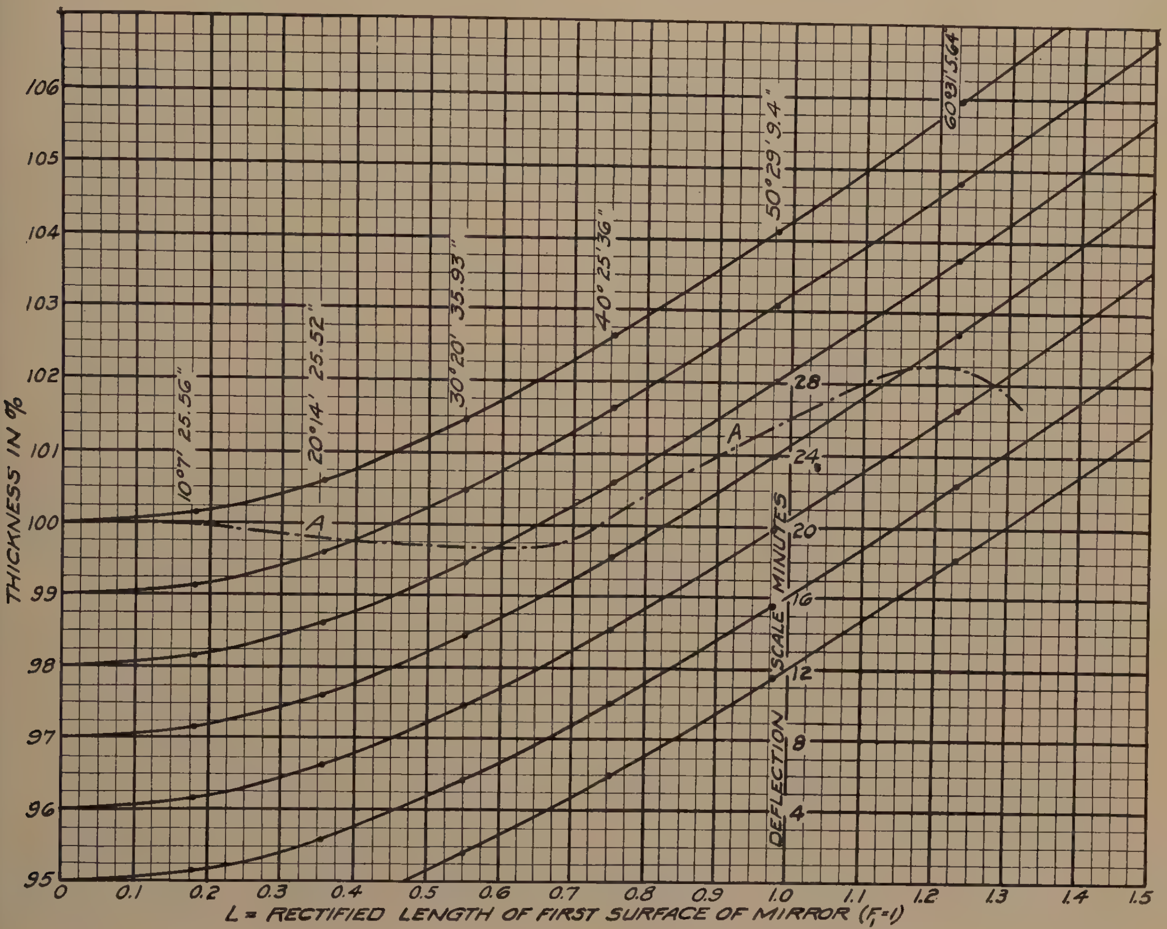


Fig. 148. The curves of this diagram give the thickness of co-paraboloidal mirrors having central thicknesses in the ratios 100, 99, 98, 97, 96, 95 and 94. By plotting the thickness of an actual mirror on this web and noting its degree of parallelism with the adjacent curves its optical accuracy can be readily computed. The angles marked on the upper curve are mid-angles between the points of entrance and exit of the same ray

the light is assumed to come from the silvered surface.

TABLE XVI

BEAM INTENSITY OF TYPICAL 60-IN. MIRROR

$T_0 = 0.0225\ F_1$

Mirror Angle $\frac{a+b}{2}$	ERRORS		PROJECTED BEAM CANDLES	
	Surface	Projection	Co-Paraboloid	Actual Mirror
15°	0°3'24"	0°11'	83,000,000	63,000,000
25°	0°7'12"	0°23'	140,500,000	70,500,000
35°	0°4'24"	0°14'	203,000,000	143,000,000
45°	0°0'56"	0° 3'	283,000,000	263,000,000
55°	0°3'45"	0°12'	387,000,000	227,000,000
			1,096,500,000	766,500,000

Loss of central intensity due to design errors = 330,000,000 candles.

The data in Table XVII are from Fig. 148, and while the accuracy is necessarily low, the results indicate sufficiently well the degree of accuracy required to gain the maximum results from a high-intensity arc and a 60-deg., 60-in. mirror corrected at 40 deg.

The loss shown in Table XVII is nearly nine per cent of the full central intensity, and this is due to surface errors that reach a maximum of 0 deg. 1 min. 15 sec. It is probably true that even with the best of care in manufacturing there will be zones in the surface that depart from true parabolism, but there is the possibility that some of the systematic errors of grinding may be an aid rather than a detriment. It has been observed in measuring a number of mirrors that there is a tendency for the edges to run thin, due possibly to the greater travel of the grinding pad over this section of the glass. This error is opposed to the design error in the 50- to 60-deg. zone, which calls for an excess in thickness (shown in Fig. 146, curve *B*), and there is the possibility of the two errors cancelling. If this occurs the greatest source of loss in this particular mirror has been eliminated and the attainment of one billion candles becomes more hopeful.

TABLE XVII

60-IN. DOUBLE PARABOLOIDAL MIRROR

$T_0 = 0.0225\ F_1$

Mirror Angle b	ERRORS		PROJECTED BEAM CANDLES	
	Surface i	Projection E	Co-Paraboloid	Double Paraboloid
15°	0°0'20"	0°1' 0"	83,000,000	83,000,000
25°	0°0'48"	0°2'30"	140,500,000	125,000,000
35°	0°0'30"	0°1'36"	203,000,000	197,000,000
45°	0°0'19"	0°1' 0"	283,000,000	283,000,000
55°	0°1'15"	0°4' 0"	387,000,000	312,000,000
			1,096,500,000	1,000,000,000

Loss of central intensity due to design errors = 96,500,000 candles.

In Table XVIII the mirror has been corrected at the 50-deg. point.

The loss of 50,000,000 candles in central intensity shows the 50-deg. point to be better suited for the correction of a 60-deg. mirror, and all things considered it gives the best combination of two paraboloids.

The influence of the errors of projection is largely a matter of the angular dimension of the normal beam. Thus it has been found that a 36-in. mirror of a design (or perhaps only execution) greatly inferior to the one just laid out will give photometric readings of 84 per cent of the full theoretical value. This same class of mirror in the 60-in. size gives only two-thirds the possible maximum. This greater loss is to be expected from mirrors giving a much narrower beam. Micrometer measurements of thickness show the 36-in. and 60-in. mirrors to be nearly identical in this feature; that is, the percentage thickness at various angular positions on the mirrors seems to be independent of the diameter and focal length.

TABLE XVIII

60-IN. DOUBLE PARABOLOIDAL MIRROR

$T_0 = 0.0225\ F_1$

Mirror Angle b	ERRORS		PROJECTED BEAM CANDLES	
	Surface i	Projection E	Co-Paraboloid	Double Paraboloid
15°	0°0'38"	0°2' 0"	83,000,000	83,000,000
25°	0°0'49"	0°2'36"	140,500,000	130,500,000
35°	0°0'49"	0°2'36"	203,000,000	183,000,000
45°	0°0'36"	0°1'54"	283,000,000	283,000,000
55°	0°0'34"	0°1'48"	387,000,000	367,000,000
			1,096,500,000	1,046,500,000

Loss of central intensity due to design errors = 50,000,000 candles.

The degree of angular accuracy necessary to obtain a certain degree of full beam intensity is rigidly related to the focal length of the mirror, assuming a uniform light source and a uniform angular opening of the mirror. The relationship is a direct-inverse function; that is, doubling the focal length requires halving the angular error, but it does not follow from this that if the angular error is doubled the loss of intensity will be exactly doubled. As a rule the loss will mount in a much greater ratio than the error, as is illustrated in Fig. 149, where the data of an actual mirror are taken as the basis of the computations. It has been found by micrometer measurements on broken mirrors that the thickness relation in a 36-in. mirror is almost exactly duplicated in a 60-in. mirror. The computations are extended to a 48-in. mirror, which is a standard size, and to an 80-in. mirror, which is a size that has been discussed but never built in this country.

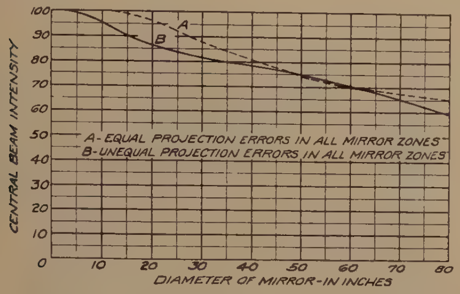


Fig. 149. Curve *A* shows how the central beam intensity of the high-intensity beam falls off when all mirror zones are in optical error to the same degree. This curve is identical in shape with the normal beam characteristic when plotted to approximate co-ordinates. Curve *B* gives the decrease of central intensity as computed for a certain typical mirror, and the data of this curve are in good agreement with the data of photometric beam tests

It will be observed that this performance curve bears a great resemblance to the brilliancy curve of the crater, Fig. 112, and to both the zonal images and the beam characteristic, Fig. 113. A little consideration of the physical relations between mirror errors and the resultant beam intensity will show that this resemblance is not an accident, but follows inevitably from the geometry of the beam. Consider the case of a mirror having a uniform angular error of 0 deg. 5 min. at all points. The individual zonal images would all be moved 0 deg. 5 min. out of line with the center of the beam, and the summation of intensity on the axis would be equal to the intensity 0 deg. 5 min. from the axis of the normal beam, n this case 810,000,000 candles for the searchlight of Fig. 113. A uniform error of 10 min. would reduce the central intensity so that of the point 10 min. from the axis of the normal beam, and we can go on with ncreasing errors and obtain a curve showing the relation of intensities to errors that is an exact duplicate in form of the ideal beam characteristic. This interesting relation between angular error and central intensity may be expressed by the equation

$$I'_0 = I_e \qquad (174)$$

where

I'_0 is the central intensity of the beam from the defective mirror
e is the constant angular error in a meridian plane of the projected light.
I_e is the intensity of the normal beam at an angle e from the axis.

There are several features about equation (174) that are of importance. In the case of the mirror previously mentioned as having different errors in the different zones, the value of I'_0 is determined by solving for the reduction in each zone, as was done in Table XVI, and the resultant beam indicates an average deflection of 0 deg. 8 min., which is the distance from the axis to where the intensity is 766,500,000 candles. But if an attempt is made to apply equation (174) directly to the case of a mirror of different focal length, for example 24 in. in diameter, it will be discovered that the results will not agree with the summation of the zonal images from the new mirror. This follows from the fact that the zonal angular errors being different in each zone change at greatly different rates, and we are not considering the intensities at a single distance from the axis, but at different distances in each case. The determination of the net result is therefore expressed by a series as follows:

$$I'_0 = Z'_{e'} + Z''_{e''} + Z'''_{e'''} + \cdots \qquad (175)$$

where

Z' is the intensity in the first zone (i.e., 10 deg. to 20 deg.) and
e' is the angular error of projection in the first zone, etc.

In Fig. 149 the curve *B* gives the computed performances of mirrors of various diameters, but all having the same series of zonal errors, as derived from the curve *A* in Fig. 148. The curve *A* in Fig. 149 is for mirrors having a uniform error of 0 deg. 8 min. in all zones. The two types of mirror give equal intensity for the 60-in. size but for other sizes they differ.

A third rate of change of I'_0 occurs when the light source is moved along the axis away from the focal point. We may in this case consider the light to be in the proper focus and the mirror zones to be defective. This case obviously falls under the head of equation (175) for each zone now has a different angular error, and each must be solved individually.

(*To be continued*)

Recent Developments in Alternating-Current Temperature Indicators for Transformers

By V. M. Montsinger

Transformer Engineering Dept., Pittsfield Works, General Electric Company

The need for a ready means to determine the operating temperature of transformers has led to the development of several types of temperature indicators. The author's purpose in this article is to inform the engineer of several supplementary developments in this type of equipment.—Editor.

Within the last two or three years several new devices have been developed for alternating-current temperature-indicator circuits. Some of these are briefly outlined in the following.

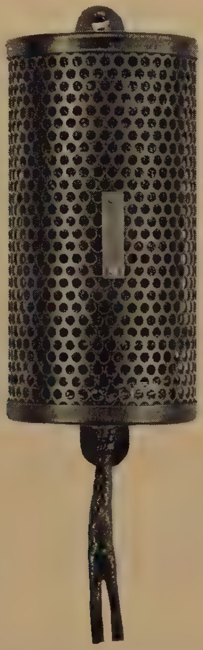


Fig. 1. Temperature Coil in Cage for Mounting in the Oil of Transformers

Temperature Coil for Reading Oil Temperatures

Under some conditions of location it is desirable to be able to make long-distance observations of transformer oil temperature. To render this service possible a standard temperature coil is wound inside a single-tube resistance cage, as shown in Fig. 1. It is a simple matter to suspend this cage under the oil, from the frame of the transformer, by means of the extension lugs at each end. So far as insulation is concerned, this temperature coil does not require an insulating transformer. However, all standard meters are calibrated with an insulating transformer connected between the temperature coil and the meter. Since the exciting current and the losses of the insulating transformer have an appreciable influence on the length of the scale plate it is necessary, if a standard meter is used, always to have an insulating transformer in the circuit. If it is not used the meter must be given a special calibration, in which case it cannot be used also to read the temperature of the transformers having an insulating transformer and a temperature coil in the windings. When the temperature coil is placed in the oil, the insulating transformer can be placed either on the inside or outside of the tank. The losses are so small that even in the air no noticeable temperature rise is produced.

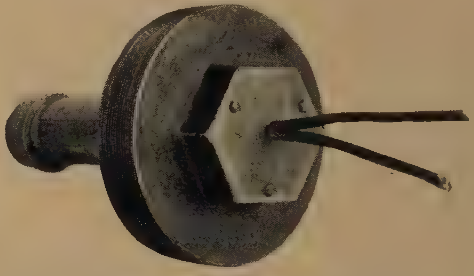


Fig. 2. Temperature Coil Encased in 2-in. Pipe and 8-in. Cap for Measuring Temperature of Ingoing Cooling Water

Coil for Observing Ingoing Water Temperatures for Water-cooled Transformers

Fig. 2 shows a temperature coil encased in a 2-in. pipe and an 8-in. cap. Due to the fact that the temperature coil itself has approximately 12 watts loss, it was found necessary to encase it in a double water pipe so arranged that water could be adjacent not only to the outside but also the inside of the pipe. The small section of pipe shown in Fig. 2 is made in this manner.

Temperature Indicator Relay

Occasionally it is found advisable to supply an attachment to an alternating-current meter for operating a relay which in turn will sound an alarm, and operate a trip coil or circuit breaker when the temperature reaches a dangerous value.

For this purpose there has recently been developed a reliable and satisfactory scheme applicable to both the direct-current and the alternating-current type of meter. This employs a small enclosed high-voltage transformer. When the indicator pointer comes under a fixed point, the voltage jumps across the gap and closes the relay circuit. The stationary side of the gap may be adjusted so as to arc over at any desired temperature. In closing the circuit the transformer excitation is cut off, so that the arcing will not continue in case the two points remain close together for any length of time.

As illustrated in Fig. 3, the meter, transformer, and relay are all contained in a single case. The same circuit that excites the indicator can be used for exciting the transformer for operating the spark-over device.

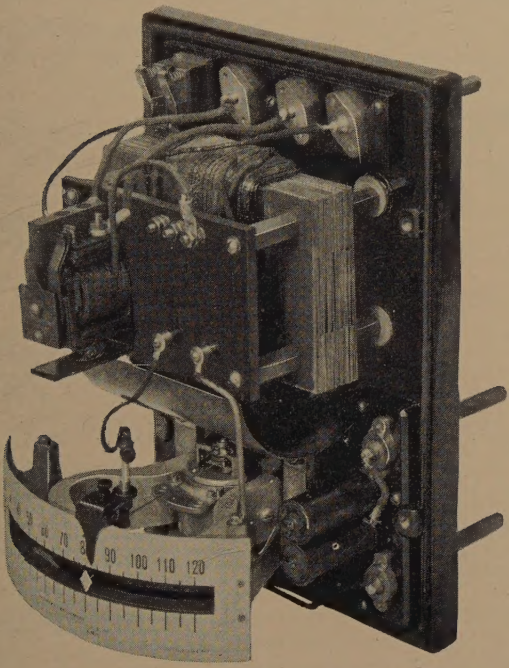


Fig. 3. Temperature Indicating Relay (cover removed)

Recording Temperature Indicating Meter

The most important recent development has been a recording meter furnished by the Leeds & Northrup Company for the alternating-current indicator circuit. This outfit is not entirely a new one, since, except for the meter, this type of recorder has been in use for several years for recording furnace temperatures by means of thermo-couples.

During the last year several of these outfits have been installed, one in the plant of a large power company. This one is used to record the temperature of three transformers simultaneously, that is, it prints the temperatures at short intervals of time on a revolving drum having a temperature chart. In this installation each transformer was equipped with two temperature coils and two insulating transformers, one of these to be used with the standard alternating-current indicating meter and the other with the recording meter. If desired, the standard recording meter can be used for recording the temperature of 16 transformers. Fig. 4 shows an interior view of the three-point recording meter as used by this power company.

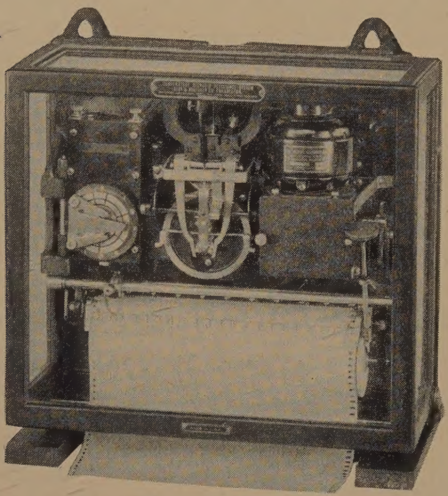


Fig. 4. Front View of Recording Temperature Indicator

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Alternators

Assembling 22,000-kv-a. Waterwheel Generator. Brown, Ralph.
Power, Aug. 19, 1924; v. 60, pp. 278-281.

Calorimeters and Calorimetry

Calorimeter for Steam Investigations Developed by Bureau of Standards. Swain, P. W.
Power, Aug. 12, 1924; v. 60, pp. 246-248.

Circuit Breakers

High-Voltage Circuit Breakers. The Operator's Viewpoint—Giving Practises, Experiences and Opinions. Jenks, J. S.
A. I. E. E. Jour., Aug., 1924; v. 43, pp. 715-718.

Electric Cables

Facts Regarding Extra High Tension Cable. Timms, M. C.
Elec. Engr., May 15, 1924; v. 1, pp. 43-49.
(Description of laying, jointing and testing the 22,000-volt cable in the metropolitan district, Melbourne, Australia.)

Underground Cable Practice in Europe. Roper, D. W.
W. Soc. Engrs. Jour., May, 1924; v. 29, pp. 217-224.
(Describes the methods of installation and operation, and compares American and European practice.)

Electric Controllers

Automatic Starting of Synchronous Motors.
Power, Aug. 19, 1924; v. 60, pp. 282-283.
(Describes a new type of controller in which the reduced voltage for starting is obtained through a reactance coil.)

Electric Drive—Paper Mills

Details of Paper-Mill Drives and Power Service. Stafford, H. E.
Ind. Engr., Aug., 1924; v. 82, pp. 360-367, 400-401.
(Discusses the transformation and distribution of electric power throughout the mill, types of motors, kinds of drive and characteristics of paper-mill loads.)

Electric Drive—Steel Mills

Electrically-driven Reversing Mills. Wright, J. D. and others.
Iron & St. Engr., Aug., 1924; v. 1, pp. 417-428.
(Gives operating data to aid in the selection of the proper equipment.)

Engine *vs.* Motor Drive for Reversing Blooming Mill. Hunt, C. H.
Iron & St. Engr., Aug., 1924; v. 1, pp. 429-432.

Electric Drive—(Steel Mills)

New 20-16 In. Hot Strip Mill. Jones, Noble and Wilson, G. P.
A. I. E. E. Jour., Aug., 1924; v. 43, pp. 710-715.
(Illustrated description of electric drive equipment.)

Electric Furnaces

Continuous Conveyor Electric Furnace Designed to Conserve Heat.
Iron Age, Aug. 14, 1924; v. 114, p. 389.
(Brief description of a furnace built by the Electric Furnace Construction Company for the Armstrong Manufacturing Company, Huntington, W. Va.)

Electric Furnace Annealing. Nutting, A. I.
Iron Age, Aug. 14, 1924; v. 114, p. 377.
(Short article presenting an analysis of operating costs for a small furnace installed in the plant of the Nutting Manufacturing Company, Worcester, Mass.)

New Norwegian Electric Pig Iron Furnace. Hodson, Frank and Sem, M.
Jour. Elec., Aug. 1, 1924; v. 53, pp. 92-93.
(Short description, with illustrations.)

Electric Motors, Induction

New Self-Excited Synchronous Induction Motor. Fynn, Val. A.
A. I. E. E. Jour., Aug., 1924; v. 43, pp. 744-748.
(Describes the construction and the performance of the motor.)

Electric Motors, Repulsion

Atkinson-Type Repulsion Machine as a Motor and Generator. Teago, F. J.
I. E. E. Jour., Aug., 1924; v. 62, pp. 720-726.
(Shows how a motor may be made to operate as a generator by means of brush shifting.)

Electric Power

Hydroelectric Practises and Equipment of the South. Thurlow, O. G. and Sirnit, J. A.
A. I. E. E. Jour., Aug., 1924; v. 43, pp. 719-723.
(On present and prospective waterpower development and superpower possibilities in the South.)

Regional Review of the Power Resources for the Pacific Coast States. Markwart, A. H. and Barre, H. A.
Jour. Elec., Aug. 15, 1924; v. 53, pp. 127-132.

Electric Transformers

Unbalance in Furnace Transformers. Starr, Eugene C.
Elec. Wld., Aug. 16, 1924; v. 84, pp. 320-322.
(Gives results of an experimental and theoretical investigation.)

Electric Transformers—Testing

Hot Spots and Overload Indicators—I. Cole, Harold.
Elec. Wld., Aug. 16, 1924; v. 84, pp. 314-317.
(Results of a series of tests conducted by the Detroit Edison Company, to determine the hottest spots in transformers, the thermal gradient between the hottest spot and oil, etc. Serial.)

Electric Transmission Lines

Comparative Costs of Tower Line Construction by Three Different Methods. Brubaker, H. S.
Elec. Lt. & Pr., Aug., 1924; v. 2, pp. 19-21, 58.

Electrical Machinery—Losses

Surface Iron Losses with Reference to Laminated Materials. Spooner, T. and Kinnard, I. F.
A. I. E. E. Jour., Aug., 1924; v. 43, pp. 723-729.
(Presents results of tests, and shows how these may be applied in design work.)

Electricity—Applications—Miscellaneous

Hatching Chicks Electrically. Bell, Harold E.
Jour. Elec., Aug. 1, 1924; v. 53, pp. 85-88.
(Illustrated description of a large hatchery, with operating statistics.)

Electrometallurgy

Case of Electric Brass Melting. June, Robert.
Iron Age, Aug. 14, 1924; v. 114, pp. 371-372.
("Production experience at Detroit plant of the Federal-Mogul Corporation.")

Frequency Changers

World's Largest Frequency Changer. West, W. B.
A. I. E. E. Jour., Aug., 1924; v. 43, p. 709.
(Brief description of the 35,000-kv-a. machine of the Brooklyn Edison Company.)

Generating Sets

Some Factors Affecting the Working Costs of Small Electric Generating Sets. Kennard, E. G.
I. E. E. Jour., Aug., 1924; v. 62, pp. 713-719.
(Includes tables and graphs showing results of tests.)

Grounding

Grounding Transformer Secondaries. Gibbs, J. B.
Power, Aug. 26, 1924; v. 60, pp. 323-324.

Hydroelectric Development

Queenston-Chippawa Development of the Hydroelectric Power Commission of Ontario. Gaby, F. A.
Engng., Aug. 15, 1924; v. 118, pp. 220-223.
(Paper read before the British Association presenting a number of the salient engineering and other features involved in the design and construction. Serial.)

Hydroelectric Plants

Combating Ice in European Hydroelectric Plant.
Engng. News-Rec., Aug. 14, 1924; v. 93, pp. 265-266.
(Gives methods employed in Norway and Sweden.)

Hydroelectric Plants, Automatic

Great Works Hydroelectric Plant Has Original Design. Andrus, R. J.
Elec. Wld., Aug. 16, 1924; v. 84, pp. 305-307.
(In this 625-kv-a. automatic station of the Berwick and Salmon Falls Electric Company, the dam, bridge and building form one structure.)

Hydroelectric Plants—Testing

Standard Tests for Hydraulic Power Plants.
I. M. E. Proc., No. 3, 1924; v. 1, pp. 283-340.
(Report of the Joint Committee of the Institutions of Civil and Mechanical Engineers.)

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(Illustrated description of the construction and behavior of a new type of high-voltage insulator.)

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Bul. of Hyd. Pr. Comm. of Ont., July, 1924; v. 11, pp. 251-262.
(Author is Distribution Engineer of the Ontario Hydroelectric System.)

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Central Station *vs.* Industrial Power Plants. Risley, Jr., W. J.
Power Pl. Engng., Sept. 1, 1924; v. 28, pp. 896-897.
(Considerations involved in determining the relative merits of the two.)

Radio Direction-Finding

Some Radio Direction-Finding Observations on Ship and Shore Transmitting Stations. Smith-Rose, R. L.
I. E. E. Jour., Aug., 1924; v. 62, pp. 701-711.
(Gives results of some experiments. Several tables shown.)

Radio Engineering

Energy of Atmospherics. Eckersley, T. L.

Elec'n, Aug. 8, 1924; v. 93, pp. 150-151, 155.

(Discusses the effect of "strays" on radio receiving apparatus. Mathematical.)

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Wireless Wld. & Radio Rev., Aug. 6, 1924; v. 14, pp. 544-545.

(Records of signal intensity in America of the short wave experimental communication between Poldhu and Marconi's yacht *Electra*.)

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(Describes an apparatus for the automatic plotting of vacuum tube characteristic curves.)

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Notes on Wireless Matters. Howe, G. W. O.

Elec'n, Aug. 8, 1924; v. 93, pp. 148-149.

(Discusses the effect of the earth in the transmission of electro-magnetic waves in radiotelegraphy.)

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Signal Development in Connection with Single-Phase Propulsion. Follett, Waldo F.

Rwy. Sig., Aug., 1924; v. 17, pp. 315-319.

("New York, New Haven & Hartford develops a-c. signaling to meet special characteristics caused by electric operation.")

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Facts Regarding the Use of Reactors. Dann, W. M.

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Bul. of Hyd. Pr. Comm. of Ont., July, 1924; v. 11, pp. 263-273.

(Theoretical article. Gives a number of curves.)

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Short Circuits of Alternating-Current Generators. Laffoon, C. M.

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Tests of a 7000-kw. Steam Turbine Generator at the Bristol Electricity Works.

Engng., Aug. 22, 1924; v. 118, pp. 253-255.

(Presents test results.)

Substations

Standardizing Small Substations. Gaylord, J. C.

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(Describes three types of stations developed by the Southern California Edison Company.)

Substations, Automatic

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Harvard Throttling Experiments Extend Data on Superheated Steam. Swain, P. W.

Power, Aug. 26, 1924; v. 60, pp. 329-332.

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(Discusses the development of thermionic valves containing such filaments.)

NEW BOOKS

Automatic Telephone Systems. Vol. 3: Large Multi-office Automatic Systems; Semi-automatic Working; Miscellaneous Systems; Layout and Wiring; Power-plant; Traffic. William Aitken. 339 pp., 1924, N. Y., D. Van Nostrand Co.

(This is the third and concluding volume of an extensive three-volume work, of British origin, on automatic telephony. It goes into considerable detail in describing the various systems and features mentioned in the volume subtitle given above. In addition to a large number of half-tone illustrations and line-cuts, the volume includes numerous folded plates showing wiring diagrams in detail. The comprehensive index necessary for a volume covering so complex a subject is also provided.)

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